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ABSTRACT

The objective of this project was to determine the need for manpower training in solar energy technology and report it on a regional and/or state basis. Three basic questions were to be answered by the project: (1) Based on a survey of solar heating and cooling systems equipment, what types of systems are being manufactured? (2) What is the quantitative demand for workers to install and maintain such equipment? and (3) What skills must be possessed by solar workers? Among the findings reported was that the typical installation time for a domestic hot water system is forty man hours, plus an additional ten man hours required for design, and two man hours per year for maintenance. An analysis of the tasks for design, installation, and maintenance for a typical solar system reveals that the solar tasks accounted for approximately 20 percent of the total task time. The remaining 80 percent of the tasks could be performed by solar-trained conventional tradesmen. To supply the required number of solar technicians and mechanics at a steady rate, a minimum of 4,000 workers must be trained every year to fulfill the increment in demand until 1985. (Appended material includes the contractors' survey form, the task inventory form, and task analysis information.) (LRA)

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AN ASSESSMENT OF NEED FOR DEVELOPING AND IMPLEMENTING TECHNICAL AND SKILLED WORKER TRAINING FOR THE SOLAR ENERGY INDUSTRY

Final Report

Prepared by
Navarro College
Corsicana, Texas

Work Performed for the Department of Energy under Contract No.
EG-77-S-04-3869

Charles G. Orsak, Jr. - Principal Investigator, Navarro College
Robert Barnstone - Economist, Management Services Associates, Navarro College
Harold Gibson - Task Analyst, Navarro College
Dr. Yashvant Jani - Manpower Assessor, Navarro College
Dr. Jeffrey Morehouse - Equipment Analyst, Texas A & M University

January 13, 1978

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U.S. DEPARTMENT OF HEALTH,
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EXECUTIVE SUMMARY

DESCRIPTION OF THE PROJECT

In order for the solar industry to be successful in stimulating commercial use of solar energy, it must provide for the development of manpower resources with the knowledge and skills to install and maintain solar systems. The significance of the demand for solar equipment and solar workers must be known before plans can be made to spend the great sums of money required to develop a curriculum to train these workers. There should be a well founded expectation that there will exist a clear demand for the training, and employment opportunities for the graduates of the training program. Heretofore, there have been insufficient data available regarding the number of solar energy workers that could be employed in this new and emerging field.

The objective of this project was to determine the national need for manpower trained in solar energy technology and report it by state. This project forecasted future manpower requirements for the solar industry by determining both the quantitative and qualitative needs for developing solar skilled manpower training programs.

Secondary objectives included the identification of the solar industry manpower populations and the identification of tasks that should be performed by solar technical and skilled workers. An analysis of this information provided the manpower population determination and should aid in solar manpower curriculum design.

The project contract had three basic tasks:

Task 1. Conduct a survey of solar heating and cooling systems equipment using ERDA, NASA, and private industry resources.

Task 2. Review existing consumer demand studies to forecast manpower requirements.

Task 3. Conduct a skills study to determine the type of curriculum required to produce the trained manpower identified in Task 2 above.

The final solar manpower assessment was formulated from the results of these three tasks.

Three separate working groups were formed to address these tasks: an equipment group, a market penetration group, and a skills analysis group. A fourth group, the manpower assessment group, combined the results from the three initial working groups to meet the overall project objectives; namely,

- To produce a forecast for solar-trained manpower needs.
- To determine the types of training required to produce manpower capable of performing the tasks identified in the task analysis.

FINDINGS

This project determined the expected time required to design, install, and maintain solar space heating and hot water systems. For this study, it was found that the typical installation time for a domestic hot water system is 40 manhours, plus an additional 10 manhours required for design, and 2 manhours per year for maintenance. The typical domestic space heating system requires 125 manhours to install, 30 manhours to design, and 10 manhours per year to maintain.

Using a task analysis approach based on the solar system design, installation, and maintenance, strictly solar tasks were identified. Using degree of difficulty and background knowledge required as the criteria, these solar tasks were found to be divided into two categories. Two types of solar workers were defined from the two categories of solar tasks: the solar mechanic and the solar technician.

The solar mechanic is defined as a conventional tradesman with knowledge of solar systems. This person is expected to perform entry level tasks of installation and routine maintenance.

The solar tasks to be performed by the solar mechanic are to:

- Mount each collector.
- Check normal positions of motorized valves and dampers.
- Monitor flowrates and temperature differentials to test system operation.

These solar mechanic tasks represent two percent of the total design, installation, and maintenance time for a typical solar energy system.

The solar technician has knowledge and skills specific to solar system design, installation, and diagnostic troubleshooting. Specifically, his solar duties and tasks are to:

- Calculate hot water load.
- Choose collector type.
- Calculate solar gain on unit area basis.
- Determine maximum available collector area.
- Determine optimum collector area.
- Design fluid flow systems.
- Check out the system powered components.
- Calibrate and test solar temperature differential controls and
- Test system operational modes.

An analysis of the tasks for design, installation, and maintenance for a typical solar system reveals that the solar tasks accounted for approximately 20% of the total task time. The remaining 80% of the above tasks could be performed by solar-trained conventional tradesmen -- the solar mechanic. The heating, ventilating, and air conditioning (HVAC) journeyman skills are needed five to six percent of the time, and are attributable mostly to design of the system. Plumbing skills for a liquid system are required approximately fifty-five percent of the time, and this same percentage applies to sheet metal skills for an air system. Lastly, electrician skills are required about four to five percent of the time, carpentry about one percent, and other skills about ten percent of the time.

The educational background needed by the solar "mechanic" to enable him to learn the required solar tasks is as follows:

(1) A high school education

(2) Experience primarily in plumbing (for liquid systems) or in sheet metal (for air systems).

Therefore, the educational background for the solar "mechanic" is nearly identical to that of the practicing plumber or sheet metal tradesman.

The educational preparation to enable the solar "technician" to perform the required tasks includes the following:

(1) A high school education

(2) Basic mathematics

(3) Basic physics

(4) Basic computer programming

(5) Basic heat transfer theory

(6) Basic fluid flow theory

(7) Drafting/blueprint reading

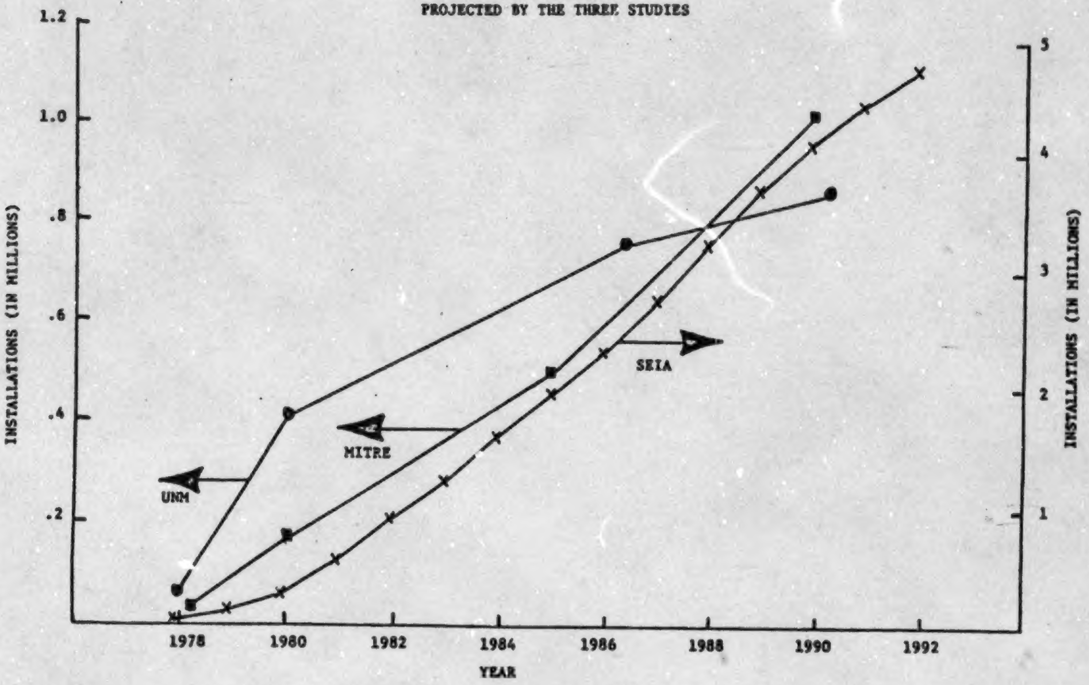
(8) Sun/earth relationships and other environmental problems

(9) Basic engineering technology.

The knowledge required of a solar "technician" exceeds that of a typical tradesman, and is beyond the high school training level.

The projected demand for solar equipment is substantial, based on three major market studies -- one produced by the MITRE Corporation, another by the University of New Mexico (UNM), and a third by the Solar Energy Industries Association (SEIA). All three studies agree that by 1985 there will be at least 2.4 million solar hot water and hot water/space heating units installed in the residential sector of the United States. Figure A compares the projections of solar installations by the three studies.

FIGURE A. COMPARISON OF NUMBER OF SOLAR SYSTEM INSTALLATIONS PROJECTED BY THE THREE STUDIES



To supply the required number of solar technicians and mechanics at a steady rate, a minimum of 4000 workers must be trained every year to fulfill the increment in demand until 1985. Of these 4000 workers, at least 800 must be trained at the solar technician level every year. In the years from 1985 to 1990, the yearly rate of supply must be increased to nearly 6200 total workers including at least 1200 solar technicians.

CONCLUSIONS

A substantial demand for trained skilled workers to design, install, and maintain solar systems will develop concurrently with the demand for solar equipment. According to the three solar market projections used, there will be at least 2.4 million solar units installed by 1985. Accordingly, by that year there must be a minimum of 25,000 skilled workers in the solar field. One-fifth of these workers must be trained at the technician level.

Solar technician training will be equivalent in length and extent to that for HVAC technicians, approximately a two year program. There is no need for as comprehensive or lengthy training for workers in the solar mechanic class. Most solar mechanic training is being done and will be done by the solar industry manufacturers, distributors, and dealers, and through short courses and continuing education. However, there is a need for an educational training program for solar mechanics if the individual does not have previous knowledge and training in HVAC and/or plumbing.

To meet the demand for solar workers, approximately 80 schools, each graduating 50 solar technicians per year, will be needed between the present and 1985. To fill the yearly demand for technicians between 1985 and 1990, 40 additional schools will be required. The regional development of these schools should follow the regional demand for installations.

Regional feasibility of solar systems will determine regional manpower demand. Solar space heating will become economically feasible among the Canadian border states in the extreme northeast and north-central parts of the nation between the present and 1980. Between 1980 and 1985, the middle belt states will show increasing feasibility. As expected, far fewer space heating systems are forecast for the southern sun belt states. Solar water heating without space heating becomes feasible in a more scattered manner. The trend for implementation varies with insolation and electric rates since hot water needs are more uniform than space heating needs.

RECOMMENDATIONS

Recommend:

1. That the solar mechanic training programs now being undertaken by solar manufacturers, distributors, and some trade unions be continued. This training should also be conducted through short courses, continuing education programs, and certificate programs.

2. That the development of solar technician training programs be begun immediately.

3. That the basic technician training program contain the flexibility to accommodate local/regional variations and future developments in the solar industry.

NAVARRO COLLEGE

ERDA CONTRACT: EG-77-S-04-3869

ASSESSMENT OF NEED FOR DEVELOPING AND
IMPLEMENTING TECHNICAL AND SKILLED
WORKER TRAINING FOR THE SOLAR ENERGY INDUSTRY

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I. DESCRIPTION OF THE PROJECT

A. STATEMENT OF THE PROBLEM

The United States is facing a major challenge in the development of alternative sources of energy to replace depleting fossil fuel reserves. Estimates of the United States Geological Survey indicate that the remaining supplies of petroleum and natural gas available domestically may be exhausted within the next 16-42 years unless other sources of energy can be utilized to meet many of our energy requirements.

Alternative sources are being developed to replace rapidly eroding domestic fossil fuel resources and to place the United States in a more tenable position from an energy standpoint. The utilization of solar energy has been given a high priority among the alternate energy sources to be developed. Congress has declared that it is the policy of the Federal Government to provide for the development and demonstration of practicable means to employ solar energy on a commercial scale. Formerly the Energy Research and Development Administration (ERDA) was stimulating private industry in the construction of residential and commercial buildings utilizing solar energy heating and cooling devices. Presently, the Department of Energy is continuing this thrust. Congress also has authorized and directed that education and technical training programs be supported to provide the necessary trained personnel for solar energy research, development, and demonstration activities required by the Solar Energy Act of 1974. The proposed National Energy Plan outlines a program of financial incentives and public education to stimulate the development of a larger solar market.

If government and industry are to be successful in stimulating commercial use of solar energy, they must provide for the development of manpower resources with the knowledge and skills to install and maintain solar systems. The significance of the demand for solar equipment and solar manpower must be known before plans are made to spend the great sums of money required to develop a curriculum to train these workers. There should be a well founded expectation that there will exist a clear demand for the training, and employment opportunities for the graduates of the training program. Heretofore, there have been insufficient data available regarding the number of solar energy system workers that could be employed in this new and emerging field.

The objective of this project was to determine the need for manpower training in solar energy technology and report it on a regional or state basis. This project forecasted future manpower requirements for the solar industry by determining both the quantitative and qualitative needs for developing solar skilled manpower training programs.

Secondary objectives included the identification of the solar industry manpower populations and the identification of tasks that will be done by solar workers. An analysis of this information provided the manpower population determination and should aid in solar manpower curriculum design.

Three basic questions were to be answered by this project:

1. Based on a survey of solar heating and cooling systems equipment, what types of systems are being manufactured?
2. What is the quantitative demand for workers to install and maintain such equipment?
3. What skills must be possessed by solar workers?

The project contract specifically called for the performance of the following tasks:

Task 1. Conduct a survey of solar heating and cooling systems equipment using ERDA, NASA, and private industry resources.

Task 2. Review existing consumer demand studies to forecast manpower requirements.

Task 3. Conduct a skills study to determine the type of curriculum required to produce the trained manpower identified in Task 2 above.

The final solar technician manpower assessment was formulated from the results of these three tasks.

B. PROJECT ORGANIZATION

The initial project organization was arranged according to the tasks described above. Three separate working groups were formed to undertake the three tasks: an equipment group (Task 1), a market penetration group (Task 2), and a skills analysis group (Task 3).

The equipment group surveyed solar equipment manufacturers and supplied information in support of the market penetration and skills analysis groups. This information included installation manuals, equipment cost, and operational data. The market penetration group produced a forecast of demand for solar equipment. Ultimately, the demand for solar manpower is a function of the demand for purchase and servicing of solar equipment. The skills analysis group determined installation and maintenance skills required for solar systems and calculated the manhour requirement per solar system.

The schematic of the overall project work plan, shown in Figure 1, represents the three phases of the project. First, each of the three groups worked independently. Upon completion of their tasks, the second phase began. A fourth group, the manpower assessment group, combined the results from the three initial working groups to meet the overall project objectives; namely,

1. To produce a forecast for solar-trained manpower needs.
2. To determine the types of training required to produce manpower capable of performing the tasks identified in the task analysis.

FIGURE 1.

SCHEMATIC OF PROJECT WORK PLAN

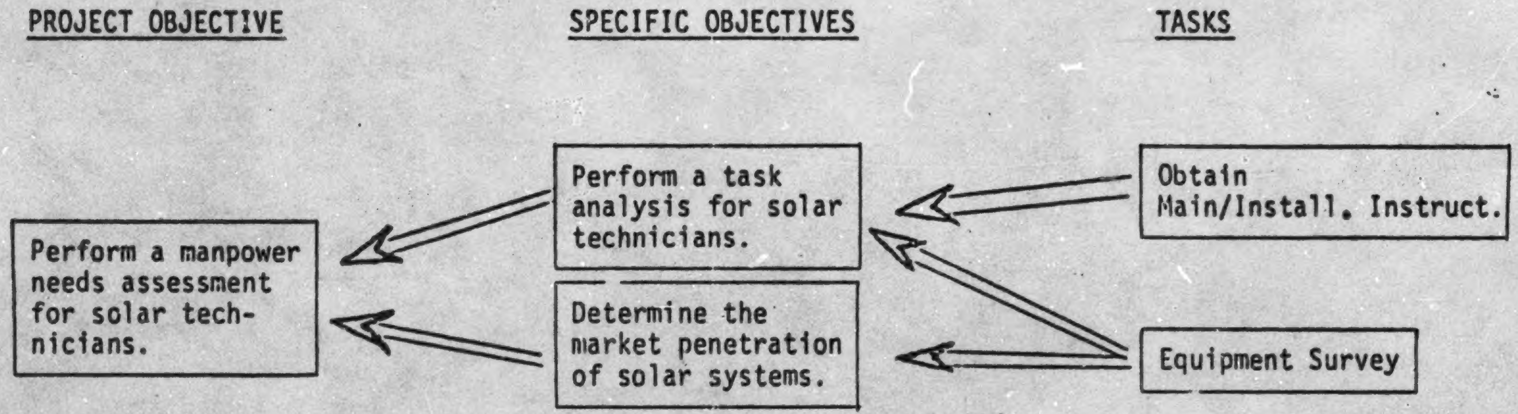

PROJECT OBJECTIVE
SPECIFIC OBJECTIVES
TASKS
Perform a manpower needs assessment for solar technicians.
Perform a task analysis for solar technicians.
Determine the market penetration of solar systems.
Obtain Main/Install. Instruct.
Equipment Survey

Figure 2, the work coordination schedule for the project, depicts the temporal and operational relationships among the working groups.

Throughout the project, an advisory committee served as on-going monitors of the progress and plans of the working groups. The advisory committee was composed of both educational and industrial professionals (members listed in Appendix A). Additionally, special consultants were utilized to identify and clarify specific problems during the course of this project. These consultants are listed in Appendix B.

C. PROJECT METHODOLOGY

In the previous section the three working groups and their interrelationships have been delineated. This section will contain a detailed description of the methodology employed by each group in carrying out its tasks.

C.1. Equipment Group

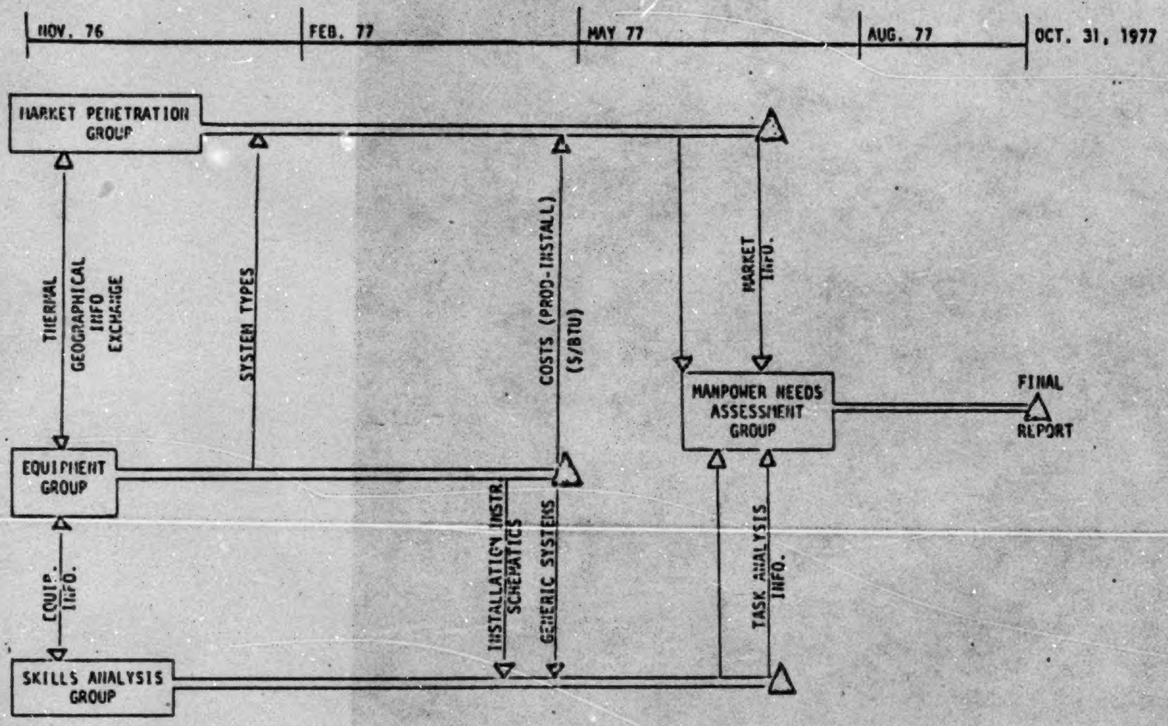
The purpose of the equipment group was to support the efforts of the market penetration group and the skills analysis group. The equipment group served as the technical consultant to the other groups, and provided information on system design, cost and deliverable energy.

The primary objective of the equipment group was to determine the types of solar systems and equipment being manufactured. Three basic constraining assumptions from several sources were made.

1. Any solar technology not presently in an "advanced" stage of development will not be widely used by 1990. (From Advisory Committee)
2. Photovoltaic systems will not be competitive with solar thermal systems before 1985. (From Advisory Committee)
3. Residential installations will comprise the majority of solar system installations. (From National Energy Plan)

FIGURE 2.

WORK COORDINATION SCHEDULE


NOV. 76
FEB. 77
MAY 77
AUG. 77
OCT. 31, 1977
MARKET PENETRATION GROUP
THERMAL GEOGRAPHICAL INFO EXCHANGE
SYSTEM TYPES
COSTS (PROD-INSTALL) ($/BTU)
MARKET INFO.
MANPOWER NEEDS ASSESSMENT GROUP
FINAL REPORT
EQUIPMENT GROUP
EQUIP. INFO.
INSTALLATION INSTR. SCHEMATICS
GENERIC SYSTEMS
TASK ANALYSIS INFO.
SKILLS ANALYSIS GROUP

Three general tasks were to:

1. Identify solar system equipment.
2. Obtain installation and maintenance instructions for existing solar equipment.
3. Determine hot water and hot water/space heating solar system sizes for various locations in the U.S.

The solar systems were first categorized by end-use application, i.e., service hot water, space heating, and space cooling systems. Within each of these categories, various generic types of systems were identified, which corresponded to the "paths to solar heating and cooling of buildings" as outlined in ERDA 76-144. "Interim Report: National Program Plan for Research and Development in Solar Heating and Cooling". (Appendix D) A survey of equipment which is presently available was conducted. Manufacturers were identified (Appendix C) and contacted through the use of ERDA listings, Solar Energy Industries Associates (SEIA) listings, advertisements in trade journals, solar conferences, and research reports. From their responses it was determined that the solar systems most likely to see widespread utilization in the next decade would be restricted to hot water and space heating application. Furthermore, the collectors used would be non-concentrating and non-tracking, but would include both air and liquid types.

The task of obtaining installation and maintenance instructions for existing solar equipment was an extension of the manufacturers' survey mentioned above. Once the manufacturers and their equipment had been identified, a representative sample of these manufacturers was recontacted and asked to supply installation/maintenance instructions to be used by the skills analysis group and cost information to be used by the market penetration group.

The third task involved estimating the collector area needed for hot water and hot water/space heating systems on a state-by-state basis. Data generated were used to determine the solar system installation times. Systems were assumed to supply 75% of the required load from solar energy. Hot water system size estimates were taken from various manufacturers' literature. Hot water/space heating system sizes were estimated by using the "Load Collector Maps" developed by Balcomb and Hedstrom (see Appendix D). A listing of approximate system sizes versus design/installation times is given in Appendix E.

C.2. Market Penetration Group

The market penetration group had the task of forecasting the demand for solar energy systems. In turn the forecasts were used to determine the number of skilled workers needed to design, install, and maintain a typical solar system. These forecasts were made for each of the contiguous states.

Existing market studies were used to project future demand for solar installations. With the help of the Advisory Committee, standards of evaluation were developed to provide a common basis of comparison for the existing studies. These market studies were reviewed, assumptions were accepted, and the specific differences in approach to forecasting demand for solar equipment were established. The detailed procedures involved in completing this task are given in Chapter II of this report.

C.3. Skills Analysis Group

The skills analysis group was to determine the number of solar workers needed to design, install, and maintain the typical solar system. Initially, this group performed a review of the product specifications, literature, schematic diagrams, and installation and maintenance instructions obtained from manufacturers. After a sufficient foundation had been developed using the available literature, a preliminary inventory of tasks was made. This task inventory consisted of a list of duties for the solar worker, under each of which was a listing of specific tasks to accomplish that duty. The methodology used in the task analysis is found in Chapter III, while the methodology used to determine manhour requirements per system is explained in Chapter II of this report.

C.4. Manpower Assessment Group

The manpower assessment group was the final working group of the project. The personnel from the initial three working groups combined the findings of their individual groups to formulate the results and conclusions of this project. The specific objectives of this group were the overall project objectives:

1. To produce a forecast of solar-trained manpower needs.
2. To determine the types of training required to produce trained manpower capable of performing the tasks identified in the task analysis.

The results concerning the task analysis and educational levels associated with the required training are found in Chapter III. The predicted manpower needs are given in Chapter II.

II: MANPOWER ASSESSMENT

The manpower assessment group utilized the pertinent results from the three individual groups described in Part I. The manpower demand of the solar energy industry is a direct function of the manhour requirement per solar system and the yearly demand for solar equipment. This chapter is divided into three sections. In section A the major existing economic studies in the solar field, which were used in this project, are described. Using these studies, the regional yearly demand for solar equipment in the U.S. residential sector is predicted and tabulated. In Section B the methods for determining the manhour requirement per solar system are outlined. In section C, manpower demand is calculated for each region for each year from 1978 to 1990.

A. PROJECTIONS OF EXPECTED DEMAND FOR SOLAR SYSTEMS

It was the basic assumption of this project that the demand for solar manpower is a direct function of the demand for solar equipment. The forecast of demand for solar equipment is based on existing studies.

A.1 SELECTION OF DATA BASE

All available market studies were reviewed and analyzed; however, only 1974 or later studies were sufficiently current to be considered for selection. The objective of this process was to obtain the best estimates of the number of solar units to be installed nationally, regionally, and state-by-state. The methodology and assumptions used in each study were analyzed to select the most reasonable approach to the problem. Some of the studies, such as the University of Delaware report (ERDA E (11-1)-2598) (See Appendix D), were not useful in this project because of insufficient information. A decision was made to use three different studies as the basis of forecasts for the number of installations in this country. These three studies were as follows:

(1) The University of New Mexico Study

Title: THE ECONOMICS OF SOLAR HOME HEATING, by William D. Schulze, Shaul Ben-David.

Date: July 1976

(2) The MITRE Corporation (MITRE) Study:

Title: AN ECONOMIC ANALYSIS OF SOLAR WATER AND SPACE HEATING

Date: July 1977

(3) The Solar Energy Industries Association (SEIA) Study:

Title: SOLAR MARKET CAPTURE AND MARKET PENETRATION, by Sheldon Butt.

Date: October 1976

The rationale for selection of above studies is as follows:

The SEIA study is the industries own estimate of its market potential. As such, it represents the views of those who most directly gain or lose depending on the accuracy of their perception.

The MITRE study is the product of the most intense effort by ERDA to date to arrive at feasibility and market penetration estimates. MITRE estimates are being used extensively by ERDA in many other analyses.

The University of New Mexico study (UNM study) forecasts the economic feasibility of solar energy state-by-state, by year, and by application. Due to exogenous variables, such as orientation and structure, freedom from obstacles, and age of the structure, economic feasibility is not readily translated to market penetration. It was necessary, for this project, to carry out an assessment of market penetration, incorporating the economic feasibility as determined by the UNM study.

Figure 3 illustrates the major differences among the three studies selected and highlights the major assumptions each study employed. The studies produced several scenarios, each with its own assumptions. The UNM study, for example, had scenarios for two different interest rates and three different estimates of solar equipment costs. The most reasonable scenarios in our opinion were selected for presentation in the table. It should not be concluded that the three forecasts would be the same even if each of the three studies was based on the same set of assumptions. Different methodologies and, more importantly, different investment criteria, cause significantly different conclusions.

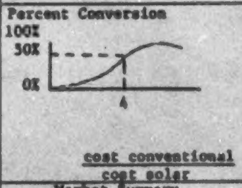
The UNM, SEIA, and MITRE studies provided regionalized results. MITRE used climatological data from sixteen different cities that represent sixteen different zones. SEIA similarly selected several regions for analysis and drew conclusions for the entire country. The UNM study provided analysis by state and by year. Since housing data are readily available by state, it was possible to make a manpower forecast, by state, for this project based on the UNM study.

A.2 CALCULATION OF THE EXPECTED NUMBER OF INSTALLATIONS USING THE UNIVERSITY OF NEW MEXICO STUDY

Estimates of the expected number of installations were made for domestic hot water systems and for domestic hot water/space heating combined systems. These two separate forecasts were made from 1978 to 1990 for each of the 48 contiguous states. Additionally, each forecast broke out the number of systems installed into two catagories: systems retrofitted to existing structures and those installed during new construction.

FIGURE 3.

ASSUMPTIONS OF THE THREE STUDIES

STUDY	COST OF SOLAR	INTEREST RATES	CONVENTIONAL FUEL PRICE	MARKET PENETRATION	TAX EFFECT
UNIVERSITY OF NEW MEXICO* *plus Navarro College's assumptions	H.W. $11/ft^2$ + $300 20 year life S.H. $9.50/ft^2$ + $1,100 fixed costs comparable typical unit, 30 year life	Real 2.5%	Computer analysis of lowest cost available fuel per M.B.T.U. by state (see table). Deregulation of natural gas.	Fraction of Market/Year H.W.: retro .018, new .27 S.H.&H.W.: retro .005, new .10 (year)	Present programs
MITRE	H.W. $20/ft^2$	Real 4%	Assume price increase of electricity at 4% greater than inflation.		National Energy Plan (40% tax credit on 1st $1000. 25% on next $6400. Declines to 25%/$1000, 15%/$6400.)
SEIA	$1,150 H.W.	Equal to long term mortgage interest rates, unspecified.	Gas supply will diminish. Prices will increase. Implied assumption all new construction will be electric: 4.5¢/KWH increasing 5% greater than inflation.	Market Summary H.W. retro / new; S.H. retro / new 1982 77.9% 12.6% 3.2% 9.5% 1987 30.4% 7.6% 19.3% 21.1 1992 10.4% 3.0% 36.5% 7.9%	Assumes National Energy Plan (40% tax credit on 1st $1000. 25% on next $6400. Declines to 25%/$1000, 15%/$6400.)

The procedure followed for calculation of the expected number of installations by state and by year was as follows:

Solar Feasibility

The year of economic feasibility for installing hot water and hot water/space heating systems by state was taken from the UNM study. These maps of solar feasibility are reproduced in Appendix F.

Housing Stock and Start Projections

The existing housing stock was determined from U.S. Census Data for single family, detached housing. The housing starts were taken from the 1972 Obers Projections for mid-point projections of gross single family, detached dwellings. These two tables are reproduced in Appendix G.

Market Penetration

The fraction of the total housing market expected to have solar systems installed, when it is economically feasible to do so, is called the market penetration. The yearly market penetration for hot water and hot water/space heating systems for both retrofit and new installations are given in Figure 4. The assumpations and reasoning used to arrive at these ratios are also given.

The multiplication of the appropriate market penetration with the appropriate housing inventory gives the number of expected installations. The number of hot water/space heating system installations expected by state and by year, for both retrofit and new installations, is given in Figure 5. The number of domestic hot water system installations was determined by reducing the market penetration for hot water systems by the number of combined hot water/space heating systems installed in the same year. Thus, Figure 6 is conservative in its expected number of hot water installations. This also explains why the number of domestic hot water systems installed decreases over time in some instances.

FIGURE 4.

MARKET PENETRATION PER YEAR

	H.W.		S.H. & H.W.	
	Retro	New	Retro	New
(a) Economic Rationality (including arch/aesth. considerations)	.80	.80	.50	.50
(b) Orientation & Struct.	.50	.50	.30	.40
(c) Age (retro-only)	.67	N.A.	.67	N.A.
(d) Free of obstacles	.67	.67	.50	.50
(e) 10% (10 yr.) conversion (retro-only)	.10	N.A.	.10	N.A.
YEARLY MARKET PENETRATION RATIO	.018	.27	.0050	.10

CALCULATION OF MARKET PENETRATION FACTORS:

(a) Econ. Rationality

- For H.W.: (new & retro): Only 20% of people will not "want" to spend the $1500, or are just against the looks of them.
- For S.H. & H.W: (new & retro): one-half the people will refuse to put out (or borrow) the money simply because of the large amount of dollars involved (approximately $6000+).

(b) Orientation & Structure

- For H.W.: Half the houses have orientation problems; no real struct. problem.
- For S.H. & H.W.: ½ have orientation problem.
  - Retro - Another 20% have structural or space problem.
  - New - 10% have space problem; no structural problems.

(c) Age

- Retro only: With 20 year solar system life, and 30 year house life, only 2/3 of housing still has necessary life left.

(d) Free of Obstacles

H.W. approximately 2/3 of all houses are free from trees, buildings, hills, etc. (S.H. has more of a problem because of more area).

(e) 10% Conversion (Retro only)

Approximately 10 years necessary to convert available market.

FIGURE 5.

EXPECTED NUMBER OF HOT WATER/SPACE HEATING SYSTEM INSTALLATIONS (In Thousands) BASED ON THE UNIVERSITY OF NEW MEXICO STUDY

	1977		1978		1979		1980		1981		1982		1983		1984		1985		1986		1987		1988		1989		1990	
	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW
AL																												
AZ																												
AR																												
CA																					23.	13.8						
CO															2.7	1.8												
CT	2.8	1.6																										
DE															.7	.5												
FL																												
GA																												
ID																												
IL																									10.9	5.2		
IN																												
IA																			3.9	4.7								
KS																												
KY																												
LA																												
ME	1.1	.2																										
MD																	4.2	3.4										
MA					4.6	2.5																						
MI															10.8	5.7												
MN					4.5	2.3																						
MS																												
MO																												
MT	.9	.2																									6.1	
NE																	2.0	.5										
NV																												

FIGURE 5 (Continued)

	1977		1978		1979		1980		1981		1982		1983		1984		1985		1986		1987		1988		1989			
	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NE
NH	.8	.6																										
NJ											6.7	4.1																
NM													1.3	.5														
NY							12.4	5.3																				
NC																												
ND	.7																											
OH																									12.4	6.1		
OK																												
OR																												
PA											14.1	5.5																
RI	.8	.3																										
SC																												
SD			.9	.01																								
TN																												
TX																												
UT													1.2	.8														
VT	.5	.2																										
VA																			5.6	4.2								
WA																												
WV																												
WI									.5	2.																		
WY,					.4	.1																						
Yearly Rate	7.6	3.1	8.5	3.1	18.0	8.	30.4	13.3	30.9	15.3	51.7	24.9	54.2	26.2	68.4	34.2	74.6	38.1	84.1	47.	107.1	60.8	107.1	60.8	130.4	72.1	136.5	74.7
Comm.	7.6	3.1	16.1	6.2	34.1	14.2	64.5	27.5	95.4	42.8	147.1	67.7	201.3	93.9	269.7	128.1	344.3	166.2	428.4	213.2	533.5	274.0	642.6	334.8	773.0	406.9	909.5	481.6
Total	10.7		22.3		48.3		92.		138.2		214.8		295.2		397.8		510.5		641.6		809.5		977.4		1179.9		1391.1	

FIGURE 6.

EXPECTED NUMBER OF DOMESTIC HOT WATER SYSTEM INSTALLATIONS (In Thousands) BASED ON THE UNIVERSITY OF NEW MEXICO STUDY

	1977		1978		1979		1980		1981		1982		1983		1984		1985		1986		1987		1988		1989		1990	
	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NE
AL																	16.7	6.3										
AZ							7.7	6.4																				
AR																	10.4	3.6										
CA							84.5	37.5													61.0	23.8						
CO																											9.6	
CT				.5			10.3	4.5																				
DE	2.4	1.3													1.7	.8												
FL							31.3	27.0																				
GA																	19.9	10.4										
ID																												
IL																												
IN																												
IA																												
KS																												
KY																												
LA																												
ME																	4.2	.5										
MD							15.3	9.4									11.1	6.0										
MA																	16.7	6.9										
MI																												
MN																												
MS																	10.8	2.9										
MO																											16.	
MT																												
NE																												
NV							1.9	1.6																				

FIGURE 6 (Continued)

	1977		1978		1979		1980		1981		1982		1983		1984		1985		1986		1987		1988		1989		199	
	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW	RET	NEW
NH																	2.8	1.6										
NJ							24.0	11.1			17.3	7.																
NM							4.7	1.3					3.4	.8														
NY	44.8	14.4					32.4	9.1																				
NC																	24.1	12.1										
ND																	2.7	—										
OH																												
OK																	14.4	4.6										
OR																												
PA																	50.8	15.1										
RI																	2.9	1.0										
SC							12.0	5.0																				
SD																	3.2	.2										
TN																												
TX																	55.2	21.8										
UT																											4.2	2.2
VT																	1.6	.6										
VA							20.0	11.4											14.4	7.2								
WA																												
WV																												
WI																												
WY																											18.0	5.5
Yearly RN & NW	47.2	15.7	47.2	15.7	47.2	15.7	246.5	125.6	246.5	125.6	239.8	121.5	241.1	121.0	240.4	121.5	445.7	195.8	440.1	191.6	416.6	177.9	416.6	177.9	416.6	177.9	464.4	190.6
Cum.	47.2	15.7	94.4	31.4	141.6	47.1	388.1	172.7	634.6	298.3	874.4	419.8	1115.5	540.8	1355.9	662.3	1801.6	858.1	2241.7	1049.7	2658.3	1227.6	1644.2	1405.5	2060.8	1583.4	2525.2	1774.0

A. 3 CALCULATIONS OF THE EXPECTED NUMBER OF INSTALLATIONS USING THE MITRE REPORT

The MITRE study predicted the expected number of installations for combined hot water and space heating and the hot water only systems for each of sixteen regions in the United States. Figure 7 and Figure 8 show these forecasts.

A. 4 CALCULATIONS OF THE EXPECTED NUMBER OF INSTALLATIONS USING THE SEIA STUDY

The SEIA study predicted the total number of expected solar installations by year for the nation. No regional forecast of installations was provided and, accordingly, no regional manpower forecast will be provided based on that study. Figure 9 shows the expected number of installations as given by the SEIA study.

A. 5 COMPARISON OF FORECASTS

Figure 10 and Figure 11 show a comparison of the expected number of installations according to each of the studies.

FIGURE 7.

YEARLY NUMBER OF INSTALLATIONS FOR SPACE HEATING (Electric) AND HOT WATER USING THE MITRE STUDY

Region	1978	1980	1985	1990
Boston	1529	3125	5735	5742
Washington	1009	2257	5610	8240
Albany	510	1103	3140	4600
Los Angeles	2885	6312	16346	19405
Charleston	1965	21444	12309	32820
Bismarck	713	1369	2801	3320
Nashville	2046	4608	15073	34900
Fort Worth	1481	3304	11790	25985
Omaha	612	1261	3505	4849
Seattle	130	346	783	1965
Phoenix	244	591	1450	3075
Miami	393	958	3945	10309
Madison	1195	2258	5051	6105
Chicago	388	658	1275	1395
Cape Hatteras	137	310	1021	2402
Atlanta	40	93	318	785
TOTAL	15273	33024	90152	165897

FIGURE 8.

YEARLY NUMBER OF INSTALLATIONS FOR DOMESTIC HOT WATER USING THE MITRE STUDY

Region	1978	1980	1985	1990
Boston	3671	6794	12057	12517
Washington	4658	9744	24778	44121
Albany	1927	3921	11053	20265
Los Angeles	11862	22308	49716	70056
Charleston	11656	25852	73341	188081
Bismarck	1952	3754	8160	14024
Nashville	12455	26496	85715	195366
Fort Worth	5415	20390	73757	160950
Omaha	2168	4423	12844	23940
Seattle	462	1021	2310	4167
Phoenix	1331	3062	7733	15936
Miami	3118	6661	24123	56500
Madison	3032	5794	14705	25874
Chicago	861	1494	2942	3625
Cape Hatteras	864	1891	6169	13840
Atlanta	244	521	1719	4020
TOTAL.	19676	144132	411122	853289

FIGURE 9.

YEARLY NUMBER OF INSTALLATIONS USING THE SEIA STUDY

Year	DHW only New & Retro	DHW & SH New & Retro	Total
78	27,600	2,400	30,000
79	103,100	4,900	108,000
80	238,200	8,800	247,000
81	523,300	18,700	542,000
82	864,500	37,500	902,000
83	1,134,800	76,200	1,211,000
84	1,445,200	145,800	1,591,000
85	1,666,800	285,200	1,952,000
86	1,797,000	518,000	2,315,000
87	1,960,000	800,000	2,760,000
88	2,067,000	1,170,000	3,237,000
89	1,988,000	1,700,000	3,688,000
90	1,656,000	2,445,000	4,101,000
91	1,277,000	3,180,000	4,457,000
92	965,000	3,800,000	4,765,000

FIGURE 10.

YEARLY NUMBER OF
SPACE HEATING/DOMESTIC HOT WATER INSTALLATIONS
(COMPARISON OF THREE STUDIES)

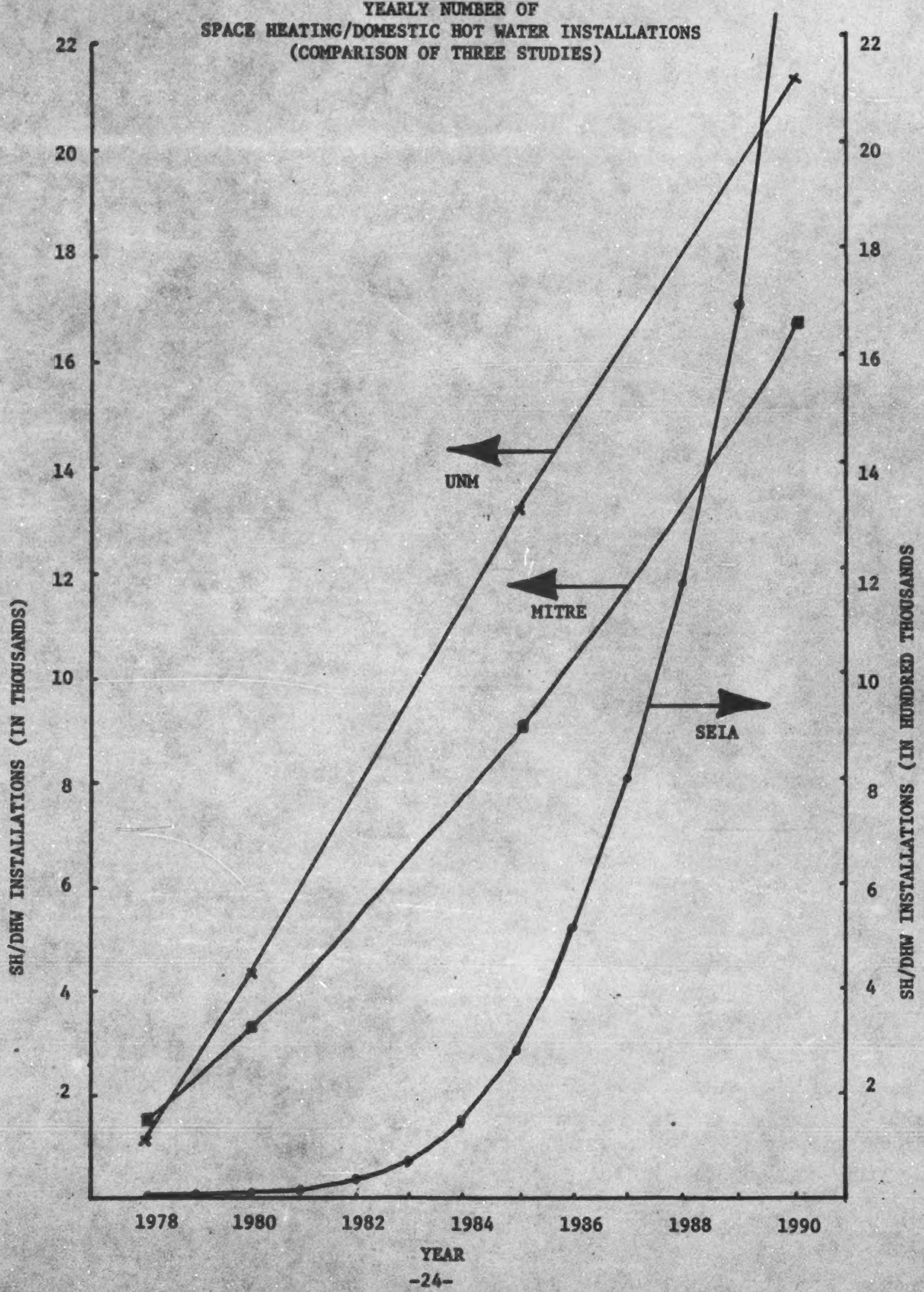
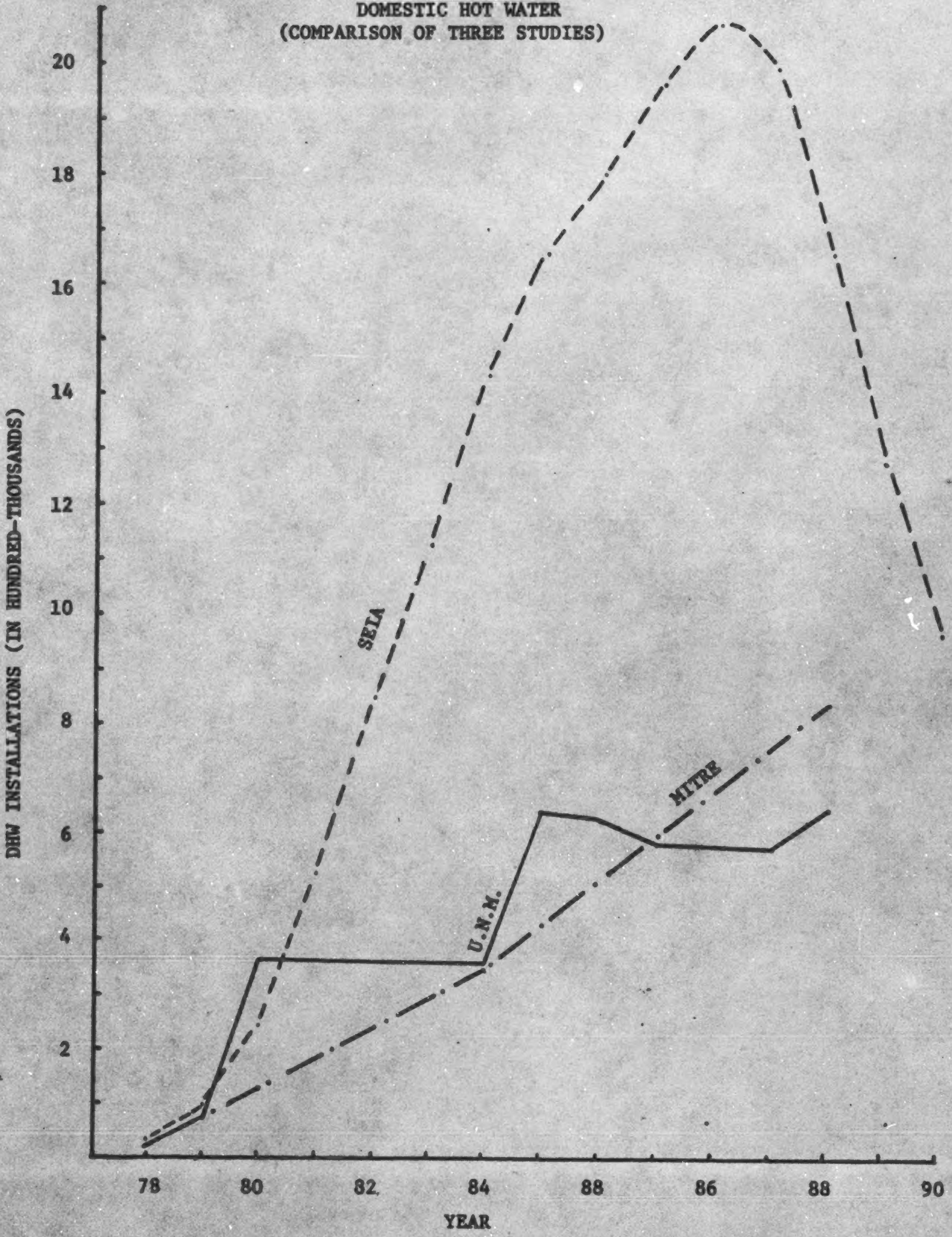


FIGURE 11.

YEARLY NUMBER OF INSTALLATIONS FOR DOMESTIC HOT WATER (COMPARISON OF THREE STUDIES)



B. MANHOUR REQUIREMENT FOR SOLAR ENERGY SYSTEMS

The determination of manhour requirement per solar system is a key to estimating the future manpower demand for the solar industry. Information obtained by the equipment group indicates that the manhour requirements occur in four phases: design time, installation time, maintenance time, and repair time. These four different times can be determined separately since each is independent. The sum of these four times is the manhour requirement per system.

B. 1. TIME DEFINITIONS

Design Time

Design time consists primarily of calculating heating load requirements, energy gain from insolation, choosing collector types and other factors concerning system design. The first solar system design a person performs will generally take longer than subsequent designs due to lack of experience. Furthermore, the design time requirement can be reduced by formulating tables of data used extensively in calculations.

Installation Time

Installation time is mainly hands-on time and requires knowledge of skills from various trades. This time depends greatly on the size of the system being installed, which includes the collector size, storage tank size, and other pertinent factors. Studies of solar energy demonstration projects and private installations indicate that the greatest varying factor in installation time is the total collector area, while the time for installing auxiliary components remains fairly constant.

Maintenance Time

Maintenance time depends more on the system complexity (whether a hot water only system or space heating and hot water combined system) than the system size.

Repair Time

The repair time depends on the type of problem encountered, which is totally unpredictable and uncontrollable, and therefore could only be estimated.

B. 2 FACTORS USED FOR TIME DETERMINATIONS

To ensure proper determination of the times for each phase, the basic information supplied by the equipment group was used, as follows:

1. The solar energy system defined as the most "typical" system uses flat-plate collectors.

2. The typical solar hot water system has 50 square feet of collector area, while the typical combined space heating and hot water system has nearly 300 square feet of collector area.

3. The optimum collector size for each State is determined from the average daily insolation, weather data, and other collector characteristics for 75% of the heating load requirements of an average single family housing unit. (Appendix E)

The equipment group also provided installation manuals and operational procedures from various manufacturers. Detailed study of design procedures combined with the above information showed that the design time for each generic type of solar system should be relatively constant. The installation time should be a direct function of total collector area since there is little time variation in the installation of auxiliary components. Thus, it is necessary to determine how the installation time varies with total collector area. The maintenance time, similar to design time, is relatively constant because it is related to system type rather than total collector area or other factors. Since it is impossible to relate repair time with any predictable factor, it is plausible to assume no time for repair and to remain conservative in the estimation of manpower requirement per solar system. Thus, the efforts in this project were directed toward determining design, installation, and maintenance time.

B. 3. METHODOLOGY FOR TIME DETERMINATIONS

There are several ways to determine time requirements. The most direct way would be to survey solar contractors and obtain information about their actual hands-on experience. Questions regarding the types of systems installed, and how much time was required in each phase, could be asked. A statistical analysis of the answers obtained could provide reliable figures for manhour requirements per system within a desired confidence level. In addition, the statistical correlation between generic type of solar system and installation time could be studied.

Another way to determine time requirements would be to survey manufacturers of solar energy equipment. Appropriate questions to ask might include: How much time is required to install your particular system (i.e., water heater or space heating system)? In terms of manhours, what are the maintenance requirements for your system? How much time does a solar contractor devote to the design of a complete system using your collectors and other components?

Responses to this type of question could be used to correctly determine the time requirement for the majority of equipment presently in use. However, the time required in each phase, as given by manufacturers, would likely be the minumum time. Manufacturers generally would not account for "overhead" time usually considered by solar contractors.

Still, the input from manufacturers could be very valuable in establishing the time requirements for the various stages of the solar systems. Appropriate averaging and correction for overhead time would give reliable information about manhours per solar system for this project. It should be noted that this source of information is completely independent from the first one.

A third method for determining time requirements, and in our view the most practical, would be to form a committee of competent persons, who have considerable practical experience as solar contractors, to obtain the time requirement for each phase. These experts could provide the most reliable data since the effects of a learning curve and other related problems would be excluded from their input.

A fourth method of obtaining the required data would be through the Task Inventory Form (Appendix K) used as a tool in completing the task analysis. The committee of experts and consultants (Appendix B) identified the tasks according to learning difficulty and gave the typical time required to perform each task. When appropriate numbers for total collector area, pump sizes, and pipeline sizes are inserted into the formula and the overall time is totaled, the time requirements for each phase are given.

During this project all four methods were used to establish the time requirement for each stage of a solar system. These results were combined with correction factors to establish the manhour requirement for solar systems and to minimize the variations in the manpower forecast.

Contractor Survey

A nationwide survey of solar contractors was made with better than 30% response. After preparing the data base, a statistical analysis was performed as described in Appendix H. There were some interesting results. The design time is constant for small variations in total collector area. For a typical domestic hot water system, the design time is between 15 and 18 hours. The design time for space heating systems varies greatly because all generic types were combined. (The installation time was found to be a direct function of total collector area.) For a typical domestic hot water system the installation time is approximately 64 hours, while for a space heating system it is between 120 and 183 hours. The maintenance time turned out to be almost constant for space heating systems while it varied somewhat for hot water systems. This is due to the variability in the maintenance data because no significant maintenance records have been kept to date.

It is important to note that the results obtained include the effect of overhead time, learning curve (experienced vs. non-experienced), generic type distinctions, and climatological effects. It was not possible to carry out statistical analysis by region because of a small sample size.

Manufacturers and Distributors Interviews

Manufacturers and distributors were interviewed for design, installation, and maintenance time. Details and responses of these interviews are described in Appendix I. It is interesting to note that manhour values for the three phases are consistently lower than the values derived by statistical analysis. The design time for domestic hot water systems is nearly two hours while the design time for space heating systems is 9 to 50 hours. This is substantially lower because a large part of design time may be absorbed by a manufacturer's design experts and computers, or distributors may handle the design for the brand of product they stock. Installation time ranges from 60 to 100 manhours for space heating systems. This broad range is expected because of the various types of solar equipment produced by manufacturers. The installation time for domestic hot water systems is from 16 to 24 manhours. The maintenance time is approximately 2 manhours per year for a hot water system and between 7 to 10 manhours per year for a space heating system. This survey has been quite useful in establishing that there is a definite amount of overhead time.

In addition to these specific questions regarding design, installation, and maintenance time for solar systems, the contractors were asked for general comments on their need for solar-trained workers. These comments were helpful in providing project personnel with an insight into the problems facing the solar contractor. (See Appendix N.)

Committee of Experienced Consultants

Persons were contacted who had designed and installed several systems and who are considered pioneers in the solar field. They were asked to define the time required in each phase for the typical domestic hot water system and the typical hot water and space heating combined system.

The concensus was that the installation time for a typical domestic hot water system is approximately 50 manhours in retrofit construction. For a space heating and hot water combined system, that time is approximately 132 manhours. For new installations these times could possibly be reduced by half, depending on the efficiency of the installers.

The design time is approximately 5 to 7 manhours for hot water and 20 to 30 manhours for space heating, if a designer has an adequate background and some experience in the field. The maintenance varies from system to system, but it is approximately 2 manhours per year for hot water and 10 to 15 manhours per year for space heating. Comparing these values with manufacturers' values it seems that manufacturers' suggested times in all phases may not account for overhead time and other factors. The variability of the data in the statistical analysis may also be explained in terms of differing efficiencies of solar installers.

Task Inventory

Using the times listed for each task in the Task Inventory (Appendix K), values for design time, installation time, and maintenance time for typical systems were obtained. The installation times for typical domestic hot water and for typical space heating and hot water combined systems are 46 to 127 manhours, respectively. These time-values are in good agreement with values obtained by statistical analysis. The design times (10 to 34 manhours for domestic hot water and space heating and hot water combined, respectively) are also in agreement with the results of the statistical analysis. The maintenance time in this case is a little higher than that from the statistical analysis because the task inventory listed in detail all tasks required for maintenance rather than only those tasks that one would normally expect to encounter.

Combined Results

Figure 12 summarizes the data obtained from the above four sources for the typcial domestic hot water system. The data for the typical space heating and hot water combined system are summarized in Figure 13. Combining the results obtained in each of the methods, the final values for manhour requirements for a typcial solar system are shown in Figure 14.

FIGURE 12.

MANHOUR REQUIREMENT FOR "TYPICAL" HOT WATER SYSTEM FROM FOUR SOURCES

PHASE	STATISTICAL ANALYSIS	MANUFACTURERS DEALERS/DISTRIBUTORS	EXPERTS	TASK INVENTORY
DESIGN	15-18	0-2	5-7	10
INSTALLATION	44	16-24	50	46
MAINTENANCE	2-7	0-2	2	1

FIGURE 13.

MANHOUR REQUIREMENTS FOR "TYPICAL" SPACE HEATING
AND HOT WATER COMBINED SYSTEM
FROM FOUR SOURCES

PHASE	STATISTICAL ANALYSIS	MANUFACTURERS DEALERS/DISTRIBUTORS	EXPERTS	TASK INVENTORY
DESIGN	24-53	9-50	20-30	34
INSTALLATION	120-183	60-100	132	127
MAINTENANCE	9	7-10	10-15	15

These values will be used in the next section to calculate the yearly manpower demand by region for the entire nation. The SEIA study made no regional forecasts. To calculate regional manpower demand, these time requirements were modified according to the appropriate total collector area required for that region and the results were combined with the regional forecast of the number of installations. Appendix E.1 lists, by state, the design and installation times required, calculated using the University of New Mexico study. Appendix E.2 lists the design and installation times, by region, calculated using the MITRE study.

FIGURE 14.

MANPOWER REQUIREMENTS FOR "TYPICAL" SOLAR SYSTEM

	DHW	DHW & SH
DESIGN	10 manhours	30 man hours
INSTALLATION	40 manhours	125 manhours
MAINTENANCE	2 manhours	10 manhours
TOTAL	52	165

C. CALCULATION OF MANPOWER REQUIREMENTS FOR THE DOMESTIC SOLAR ENERGY INDUSTRY

The conceptual formula used in this project for calculating the yearly manpower requirements (not incremental) is given as follows:

$$\text{Yearly manpower} = \frac{I_n \times (T_d + T_i)}{1735} + \frac{I \times T_m}{1735}$$

Where I_n = Number of installations in year n
T_d = Hours required to design typical system
T_i = Hours required to install typical system
I = Total number of solar systems installed to date
T_m = Average maintenance time per system per year

The figure 1735 represents the number of hours that the typical tradesman works per year according to the Bureau of Labor Statistics.

C. 1 MANPOWER FORECAST BASED ON THREE MARKET STUDIES

Each market study used a different regional base. The University of New Mexico forecast was based on a state by state analysis. The MITRE Report divided the country into sixteen environmentally homogenous regions and made forecasts by those regions. The SEIA report made only national forecasts. Accordingly, the manpower forecasts are made on the same regional base as the demand for the solar equipment predicted by the three market studies.

The manpower demand using the University of New Mexico study as a base are shown in Figure 15 for space heating and domestic hot water systems and in Figure 16 for domestic hot water systems. These forecasts are by state, by year, from 1978 to 1990. The incremental manpower demand is shown on the bottom line. This number is the estimate of new workers required for the corresponding year. Manpower demands,

FIGURE 15.

MANPOWER DEMAND FOR SPACE HEATING AND DOMESTIC HOT WATER SYSTEMS BY STATE (In Thousands) BASED ON THE UNIVERSITY OF NEW MEXICO STUDY

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
AL														
AZ														
AR														
CA											3266	3478	3690	3903
CO								485	511	537	563	589	615	641
CT	550	575	601	626	651	677	702	727	753	778	803	829	854	880
DE								136	142	149	156	163	170	177
FL														
GA														
ID														
IL												2072	2165	2258
IN														
IA										1099	1149	1198	1248	1297
KS														
KY														
LA														
ME	36	44	51	59	66	74	81	89	96	104	111	119	126	134
MD									858	903	946	919	1034	1078
MA			895	936	976	1017	1058	1099	1140	1181	1222	1263	1304	1345
MI								2188	2284	2379	2474	2569	2664	2739
MN			894	933	972	1011	1050	1089	1129	1168	1207	1246	1285	1324
MS														
MO														
MT	134	140	146	153	159	165	172	178	184	191	197	203	210	216
NE									773	793	813	833	854	874
NV														

FIGURE 15 (Continued)

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
NH	189	197	205	213	221	229	237	246	254	262	270	278	286	294
NJ						1276	1338	1401	1463	1525	1587	1650	1712	1774
NM							174	184	195	205	216	226	236	247
NY				2364	2466	2568	2670	2772	2874	2976	3078	3180	3282	3384
NC														
ND	90	94	98	102	106	110	114	118	122	126	130	134	138	142
OH													2379	2485
OK														
OR														
PA						2519	2632	2745	2858	2971	3084	3197	3310	3423
RI	136	143	149	155	162	168	174	180	187	193	199	206	212	218
SC														
SD		109	110	111	111	112	112	113	113	114	115	115	115	116
TN														
TX														
UT							218	229	241	252	265	276	287	299
VT	96	100	104	108	112	116	120	124	129	133	137	140	145	148
VA										1078	1146	1203	1259	1316
WA														
WV														
WI					330	344	359	373	388	402	416	431	445	449
WY			56	59	62	65	68	71	74	77	80	82	85	88
Total	1231	1402	3309	5819	6394	10451	10852	14547	16768	19596	23629	26599	30110	31269

FIGURE 16.

MANPOWER DEMAND FOR DOMESTIC HOT WATER SYSTEMS BY STATE (In Thousands) BASED ON THE UNIVERSITY OF NEW MEXICO STUDY

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
AL									689	716	742	769	795	822
AZ				406	422	439	455	471	487	503	519	535	552	568
AR									420	436	452	468	484	500
CA				3586	3727	3867	4008	4149	4289	4430	3322	3419	3517	3614
CO														297
CT				461	477	494	511	527	544	561	578	594	611	628
DE	115	119	123	127	131	135	139	102	105	108	111	114	116	119
FL				1714	1781	1847	1914	1981	2048	2115	2181	2249	2315	2382
GA									908	943	977	1012	1046	1081
ID														
IL														
IN														
IA														
KS														
KY														
LA														
ME									152	157	162	167	172	178
MD				769	797	825	853	882	758	778	797	817	837	856
MA									762	789	816	843	870	897
MI														
MN														
MS									411	426	442	457	473	488
MO														614
MT														
NE														
NV				103	107	111	115	119	123	127	131	135	139	143

FIGURE 16 (Continued)

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
NH									142	147	152	158	163	168
NJ				1092	1133	797	824	852	880	907	935	963	990	1018
NM				173	180	187	135	139	144	149	153	158	163	167
NY	1911	1979	2047	1476	1523	1571	1619	1667	1715	1763	1810	1858	1906	1954
NC									1085	1126	1168	1209	1251	1294
ND									83	86	89	92	95	97
OH														
OK									591	613	635	657	679	701
OR														
PA									2051	2127	2203	2279	2355	2431
RI									124	128	133	137	142	147
SC				510	529	549	568	588	607	627	647	666	686	705
SD									102	106	110	114	118	122
TN														
TX									2308	2397	2485	2574	2663	2752
UT														188
VT									77	80	83	86	89	92
VA				977	1014	1050	1086	1123	1159	854	879	903	928	953
WA														
WV														
WI														731
WY														
Total Man	2026	2098	2170	11394	11821	11872	12228	12600	22764	23198	22714	23435	24156	26708
Incremental manpower demand	+72	+72	+72	+9224	+427	+51	+356	+372	+10164	+434	-484	+721	+721	+2552

using the MITRE forecasts for solar equipment as a base, are shown in Figure 17 (domestic hot water systems) and Figure 18 (space heating and hot water combined).

Figure 19 shows manpower demand based on the SEIA forecasts of solar systems.

C. 2 COMPARISON OF MANPOWER FORECASTS

It should be noted that the MITRE study shows at least some market penetration throughout the country whereas the University of New Mexico report shows no market penetration where their economic analysis shows that solar is not feasible.

For comparison purposes, the three forecasts are plotted together in Figure 20 on a yearly basis.

FIGURE 17.

MANPOWER DEMAND FOR DOMESTIC HOT WATER SYSTEMS BASED ON THE MITRE STUDY

(In Thousands)

Region	1978	1980	1985	1990
Boston	114	215	414	462
Washington	145	308	914	1,627
Albany	60	128	408	748
Los Angeles	383	734	1,892	2,665
Charleston	363	818	2,706	6,938
Bismarck	59	119	292	501
Nashville	388	845	3,006	7,207
Fort Worth	293	641	2,721	5,937
Omaha	67	135	474	883
Seattle	14	42	83	149
Phoenix	40	95	277	570
Miami	101	204	918	2,150
Madison	94	190	542	954
Chicago	26	46	105	130
Cape Hatteras	27	60	228	511
Atlanta	8	16	128	150
TOTAL	2,182	4,596	15,108	31,582

FIGURE 18.

MANPOWER DEMAND FOR SPACE HEATING/DOMESTIC HOT WATER SYSTEMS
BY REGION
BASED ON THE MITRE STUDY
(In Thousands)

Region	1978	1980	1985	1990
Boston	151	326	673	839
Washington	96	227	606	1,018
Albany	53	120	362	603
Los Angeles	297	644	1,798	2,565
Charleston	171	410	1,222	3,362
Bismarck	74	149	336	471
Nashville	190	452	1,556	3,830
Fort Worth	138	326	1,212	2,878
Omaha	63	137	405	644
Seattle	12	33	84	217
Phoenix	21	54	145	326
Miami	34	87	372	1,032
Madison	123	247	600	855
Chicago	42	75	160	210
Cape Hatteras	13	31	107	246
Atlanta	4	10	34	87
TOTAL	1,482	3,328	9,672	19,184

FIGURE 19.

MANPOWER DEMAND BY YEAR
BASED ON THE SEIA STUDY

Year	DHW			DHW & SH			Total
	D&I	M	Total	D&I	M	Total	
78	795	32	827	214	228	442	1,269
79	2,971	151	3,122	438	256	684	3,806
80	6,865	425	7,290	786	307	1,093	8,383
81	15,081	1,029	16,110	1,670	415	2,085	18,195
82	24,914	2,026	26,940	3,350	631	3,981	30,921
83	32,703	3,334	36,037	6,807	1,070	7,877	43,914
84	41,648	5,000	42,148	13,025	1,910	14,935	57,083
85	48,035	5,256	53,291	25,479	3,554	29,033	82,324
86	51,787	7,327	59,114	46,277	6,540	52,817	111,931
87	56,484	9,595	66,079	71,470	11,151	82,621	148,700
88	59,568	11,978	71,546	104,524	17,894	122,418	193,964
89	57,291	14,270	71,561	151,873	27,692	179,565	251,126
90	47,723	16,179	63,902	218,429	41,785	260,214	324,116
91	36,801	17,651	54,452	284,092	60,113	344,205	398,657
92	27,810	18,763	46,573	339,481	82,015	421,496	468,069

FIGURE 24.

DEMAND FOR SOLAR TECHNICIANS BY STATE BASED ON THE UNIVERSITY OF NEW MEXICO STUDY

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
AL									138	143	148	154	159	164
AZ				81	84	38	91	94	98	101	104	107	110	114
AR									84	87	90	94	97	100
CA				717	745	773	802	830	858	886	1317	1380	1441	1504
CO								97	102	107	113	118	123	188
CT	110	115	120	217	225	234	242	250	261	268	289	284	293	302
DE	23	23	25	25	26	27	28	47	49	52	53	56	57	59
FL				343	356	369	383	396	410	423	436	450	463	476
GA									182	189	195	202	209	216
ID														
IL												614	633	645
IN														
IA										220	230	240	250	259
KS														
KY														
LA														
ME	7	9	10	12	13	15	16	18	49	52	54	57	59	63
MD				154	159	165	171	176	332	337	348	347	374	387
MA			179	187	195	203	212	220	380	394	207	422	435	448
MI								438	457	476	495	514	513	552
MN			179	187	194	202	210	218	227	234	241	249	257	265
MS									82	85	88	91	95	98
MO														123
MT	27	28	29	31	32	33	34	36	37	38	39	41	42	43
NE									155	159	163	167	171	175
NV				21	21	22	23	24	25	25	26	27	28	29

FIGURE 24 (CONTINUED)

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
NH	38	39	41	43	44	46	47	49	79	81	88	88	90	93
NJ				218	227	794	433	450	469	486	504	523	540	559
NM				35	36	37	62	65	68	71	74	77	80	82
NY	382	396	409	768	798	828	858	888	918	948	978	1008	1037	1068
NC									217	225	234	242	250	259
ND	18	19	20	20	21	22	23	24	41	42	44	45	47	47
OH													476	497
OK									118	123	127	131	136	140
OR														
PA						504	526	549	982	1019	1058	1095	1133	1171
RI	27	29	30	31	32	34	35	36	62	63	67	68	70	73
SC				102	106	110	116	118	121	125	129	133	137	141
SD		22	22	22	22	22	22	23	43	44	45	46	47	47
TN														
TX									462	479	497	515	533	550
UT							44	46	48	50	53	55	57	98
VT	19	20	21	22	22	23	24	25	40	43	44	45	47	48
VA				195	203	210	217	225	232	387	405	422	438	454
WA														
WV														
WI					66	69	72	75	78	80	83	86	89	237
WY			11	12	12	13	14	14	15	15	16	16	17	18

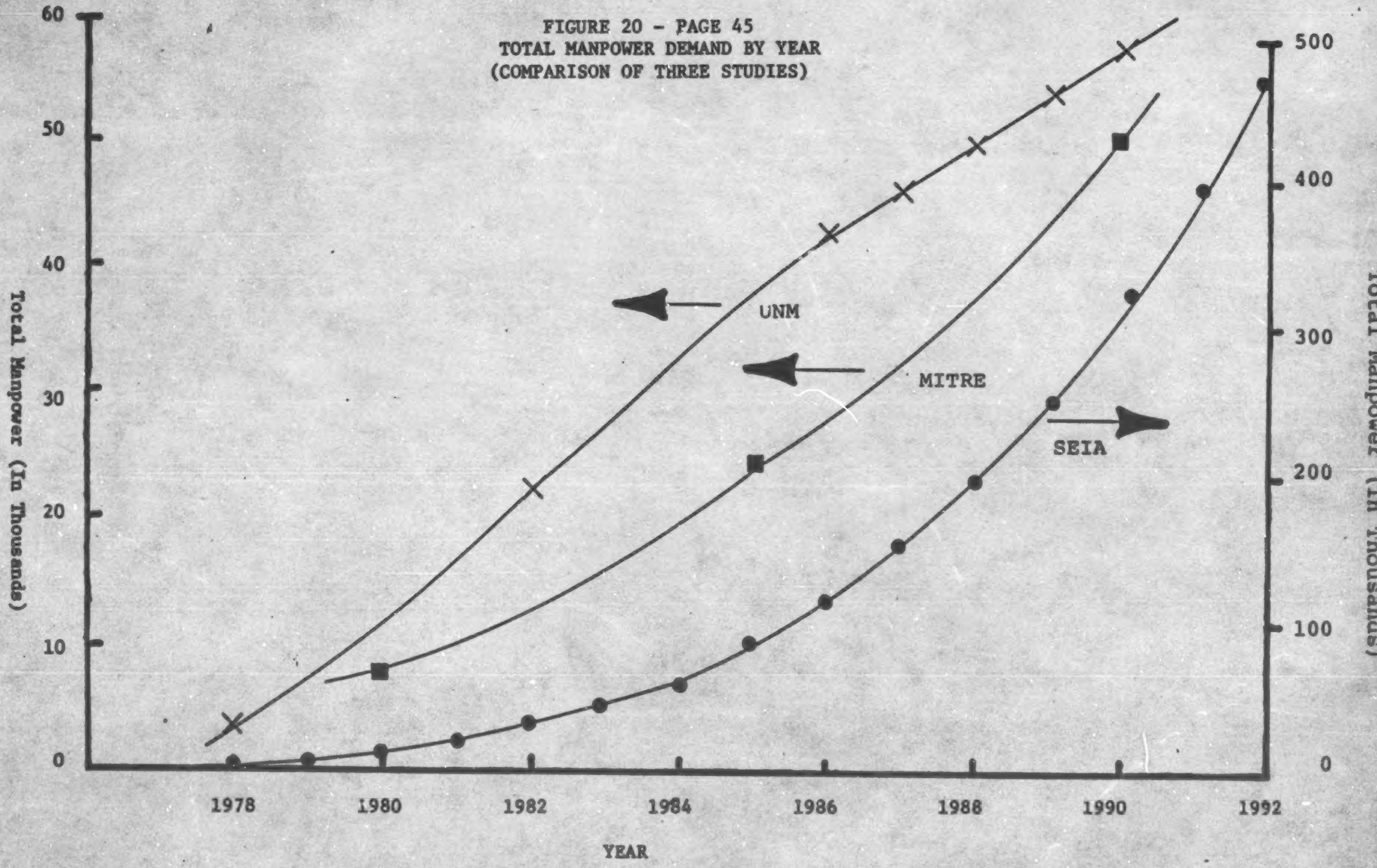


FIGURE 20 - PAGE 45
TOTAL MANPOWER DEMAND BY YEAR
(COMPARISON OF THREE STUDIES)

III: SKILLS ANALYSIS

The Skills Analysis Group had as a primary task the determination of the solar-trained, skilled manpower required per solar system for design, installation, and maintenance. A secondary task was the determination of the tasks performed by and skills required of the trained manpower so that material that should be included in a solar technology curriculum would be available should the need for such a curriculum be established.

A. DEVELOPMENT OF TASK ANALYSIS

In this section, a contractor survey is described which was used to identify the manhours required for the design, installation, and maintenance per solar system. Then a task inventory is described which was developed to list the tasks performed by solar workers. Finally, a task analysis is described which was developed by further breaking down the tasks into all the steps (activities) required for the design, installation, and maintenance of solar systems.

A.1. CONTRACTOR SURVEY

The Contractor Survey form (Appendix J) was designed to obtain total job manhours for the design, installation, maintenance, and repair of solar energy systems. It was also expected to identify the most experienced solar contractors who would be asked to confirm the task inventory.

The Contractor Survey form included an information page and checklist for the type of system the respondent had last installed. The respondent was asked to describe the system he last installed and to supply overall manhours for the design, installation, maintenance, and repair of that system. The respondent was also questioned regarding the number of solar installations he had completed. The answer to this question was an important consideration in the determination of the most experienced professionals for completing the Task Inventory at a later date. Lists of solar contractors were obtained from several sources, including the Solar Energy Industries Association, National Solar Heating and Cooling Information Center, HUD and ERDA demonstration projects, and various state solar energy societies. More than 650 Surveys were mailed to solar contractors, and more than 30% were returned. This is considered an excellent response for mailed questionnaires.

The Contractor Survey provided the total manhours for installation, and maintenance of a number of systems of varying size. It also provided a check on other inputs to manhour requirements.

More than 90% of the systems reported were flat-plate collector installations. Of these approximately 70% were liquid systems. Based on this sampling, it was decided that the "typical/average" system would be a flat-plate, liquid collector, and times listed in the Task Inventory and activities listed in the Task Analysis are biased toward flat-plate, liquid systems.

A.2. TASK INVENTORY

A task inventory form was prepared which listed all the major duties and associated tasks for the design, installation, and maintenance of solar domestic hot water, heating and cooling systems. This Task Inventory is shown as Appendix K.

Three questions were asked for each task statement on the Task Inventory form.

1. How many people are required to carry out the task?
2. How much time is required to carry out the task?

3. How difficult is it for a person to learn how to do the task? "Learning Difficulty" was denoted on three levels -- 1, 2, or 3, depending on whether the task was 1 - easy to learn; 2 - moderately difficult to learn; 3 - difficult to learn.

The Task Inventory was circulated to people attending solar seminars and was mailed to people in the solar industry to obtain their evaluation of the inventory and their response to the three questions for each task statement. The return was poor. Another way to obtain the answers needed, suggested by the project Advisory Committee, was to assemble a panel of consultants to provide the necessary answers. Consultants were chosen who had been involved with the installation of large numbers of solar systems. The panel provided answers to the three questions and confirmed the task list. In addition, each task statement was classified as to the trade which traditionally might perform that task.

Two valuable services were performed by the panel. First, the summation of all the individual task times agreed with the total job times obtained from the Contractor Survey and was thus a check against that input. Second, the classification of each task statement as to the trade that normally or traditionally might perform that task made possible a comparison of learning levels for a type of tradesman. This comparison is discussed in Section B. The Task Inventory served as a basic structure from which the Task Analysis was derived.

A.3. TASK ANALYSIS

The purpose of the Task Analysis (Appendix L) was to provide a detailed listing of the steps typically performed for the design, installation, and maintenance of a solar system, so that a solar technology curriculum could be developed should the need for such a curriculum be established. This Analysis also lists tools and equipment, materials and components, required science and mathematics, and a performance objective for each of the duty statements. The solar tasks were taken directly from the Task Inventory and are listed as Appendix M. For each activity statement the science and mathematics skills are given in that Inventory.

Any task analysis consists of a listing of duties required to accomplish a job. Further breakdown of the duties are called tasks. Breakdown of the tasks into steps are generally called activities.

B. ASSIGNMENT OF TASKS TO TRADES

Each task statement in the Task Inventory was labeled and attributed to the tradesman who normally or traditionally might perform that task. This made possible the formation of two matrices (Figure 21 and Figure 22) which can be used to compare the learning difficulty levels with the type of tradesman for solar design, installation, and maintenance. The times given apply to a system consisting of space heating plus domestic water heating. It is a "typical" system utilizing 300 square feet of water collectors.

B.1. TRADE MATRICES

Down the left side of each matrix is listed the tradesman who would be expected to do the type of work for each task. Across the top are the "Learning Difficulty" levels as given in column 3 of the Task Inventory. Each "level" is further broken down into Design, Installation, and Maintenance (denoted by Des., Ins., and Mtn.). In Figure 22, man-minutes are listed for a flat-plate, liquid system. These times were taken directly from the Task Inventory, and are listed on the matrix according to tradesman and learning level (which is further separated into design, installation, and maintenance). The percentages, shown in parentheses in each square, were obtained by summing all the times (Des., Ins., and Mtn.) in the square

FIGURE 21.
TRADE MATRIX, FLAT PLATE - LIQUID SYSTEM

	LEVEL 1			LEVEL 2			LEVEL 3			TOTALS		
	Des.	Ins.	Mtn.	Des.	Ins.	Mtn.	Des.	Ins.	Mtn.	Des.	Ins.	Mtn.
SOLAR	185	30	0	215	120	120	1175	240	0	1575	390	120
	215 (2.3%			455 (4.9%)			1415 (15.2%)			2085 (22.4%)		
HVAC	215	5	0	285	60	0	0	0	0	500	65	0
	220 (2.4%)			345 (3.7%)						565 (6.1%)		
PLUMBER	0	1200	560	0	2040	48	0	1200	0	0	4440	608
	1760 (18.9%)			2088 (22.4%)			1200 (12.9%)			5048 (54.2%)		
SHEET METAL	0	0	0	0	0	0	0	0	0	0	0	0
ELECTRICIAN	0	0	0	0	0	0	0	480	0	0	480	0
							480 (5.2%)			480 (5.2%)		
CARPENTER	0	100	0	0	0	0	0	0	0	0	100	0
	100 (1.1%)									100 (1.1%)		
OTHER	0	0	185	0	840	0	0	0	0	0	840	185
	185 (2.0%)			840 (9.0%)						1025 (11.0%)		
TOTAL	400	1335	745	500	3060	168	1175	1920	0	2075	6315	913
	16.1%	53.8%	30.1%	13.4%	82.1%	4.5%	38.0%	62.0%		22.3%	67.9%	9.8%
	2480 (26.7%)			3728 (40.0%)			3095 (33.3%)			9303 (100%)		

FIGURE 22.
TRADE MATRIX, FLAT PLATE - AIR SYSTEM

	LEVEL 1			LEVEL 2			LEVEL 3			TOTALS		
	Des.	Ins.	Mtn.	Des.	Ins.	Mtn.	Des.	Ins.	Mtn.	Des.	Ins.	Mtn.
SOLAR	185	30	0	215	120	120	1175	240	0	1575	390	120
	215 (2.1%)			455 (4.4%)			1415 (13.6%)			2085 (20.1%)		
HVAC	215	5	0	285	60	0	0	0	0	500	65	0
	220 (2.1%)			345 (3.3%)						565 (5.4%)		
PLUMBER	0	120	15	0	240	0	0	0	0	0	375	0
	135 (1.3%)			240 (2.3%)						375 (3.6%)		
SHEET METAL	0	1440	60	0	2820	0	0	1440	0	0	5700	60
	1500 (14.4%)			2820 (27.1%)			1440 (13.9%)			5760 (55.4%)		
ELECTRICIAN	0	0	0	0	0	0	0	480	0	0	480	0
							480 (4.6%)			480 (4.6%)		
CARPENTER	0	100	0	0	0	0	0	0	0	0	100	0
	100 (1.0%)									100 (1.0%)		
OTHER	0	0	185	0	840	0	0	0	0	0	840	185
	185 (1.8%)			840 (8.1%)						1025 (9.9%)		
TOTAL	400	1695	260	500	4080	120	1175	2160	0	2075	7950	365
	17.0%	72.0%	11.0%	10.6%	86.8%	2.6%	35.2%	64.8%		20.0%	76.5%	3.5%
	2355 (22.7%)			4700 (45.2%)			3335 (32.1%)			10390 (100%)		

and dividing by the total job time, shown in the bottom, right-hand square.

In Figure 22 the same data are shown for a flat-plate, air system rather than liquid. Note that for the liquid system, no sheet metal man is required, but the plumber is still required for the air system because of the need for domestic hot water. (The matrices do not include time for design or installation of the conventional auxiliary system; otherwise the HVAC and sheet metal personnel times would be increased significantly.)

For either system, some interesting observations can be made. First, the "solar" skills are needed a little more than 20% of the time. Second, the HVAC journeyman skills are needed 5% to 6% of the time, nearly entirely during the design of the system for calculations of the space heating and space cooling loads. Third, plumbing skills for a liquid system are required approximately 55% of the time, and this same percentage applies to sheet metal skills for an air system. Last, electrician skills are required about 4% to 5% of the time, carpentry about 1%, and other (i.e., the homeowner, general laborer, commercial insulator, etc.) skills are required about 10% of the time.

Of the total time required, approximately 25% involves Level 1 tasks, 45% Level 2, and 30% Level 3. Also, of the total time, approximately 20% involves design skills, 70% installation skills, and 10% maintenance skills.

It must be remembered that these figures apply to a "typical" system of approximately 300 square feet of collector area.

In some cases, tasks or skills attributed to one trade could just as easily have been attributed to another. For example, some wiring tasks could have been assigned to an HVAC journeyman rather than to an electrician.

B.2. CONCLUSIONS DRAWN FROM MATRICES

Conclusions to be drawn are that the plumber (for liquid systems) and the sheet metal worker (for air systems) already possess better than 50% of the skills required to install a solar heating and cooling system. The "solar" skills are required only 20% of the time and are primarily design skills requiring a fairly high level of scientific and mathematical knowledge.

C. "SOLAR" TASKS

From the task analysis, the "solar" tasks were identified (Appendix M) and assigned to either the "Mechanic", or the "Technician".

The tasks which were assigned to the solar "mechanic" are referenced to the Task Inventory (Appendix K) described previously. These tasks, taken directly from the Inventory, are as follows:

(a) Under the Installation Stage -

J.3: Mount each collector.

(b) Under Maintenance -

M.12: Check normal positions of motorized valves and dampers.

M.13: Monitor flowrates and temperature differentials to test system operation.

The tasks assigned to the solar "technician" are also referenced to the Task Inventory. Basically, the "technician" is responsible for the design phase and overall system check-out. Specifically, these duties and tasks are as follows:

(a) Under the Design Stage -

A: Calculate hot water load.

D: Choose collector type.

E: Calculate solar gain on unit area basis.

F: Determine maximum available collector area.

G: Determine optimum collector area.

H: Design fluid flow systems.

(b) Under the Installation Stage -

L.1: Check out the system powered components.

L.4: Calibrate and test solar temperature differential controls and test system operational modes.

If the times required for performing each task assigned to the solar "mechanic" are summed and that sum is divided by the total time required to produce the "Typical" solar energy system (as defined in Chapter II), the result will show that only approximately 2% of the time is devoted to these lower level (installation/maintenance) "solar" tasks.

A similar calculation made for the tasks assigned to the solar "technician" indicates that approximately 20% of the time to produce the "typical" solar energy system is devoted to these higher level (design/installation) "solar" tasks. (See Figure 23.)

D. EDUCATIONAL REQUIREMENTS

D.1 SOLAR MECHANIC TRAINING

A solar "mechanic" is a person who is expected to perform entry level tasks of installation and routine maintenance on solar energy systems.

The educational background required for the solar "mechanic" to be able to learn the above "solar" tasks is as follows:

(1) A high school education

(2) Experience primarily in plumbing (for liquid systems) or in sheet metal (for air systems)

Thus, the educational background for the solar "mechanic" is the education of the practicing plumber or sheet metal tradesman. The conventionally trained tradesman in plumbing, sheet metal, or heating, ventilating, and air conditioning can be taught to perform the 2% "solar" tasks in order to serve as a solar "mechanic".

A program to train solar mechanics who have no trade experience or

FIGURE 23

SOLAR TASKS BY LEVEL AND TIME
FLAT-PLATE - LIQUID SYSTEM (TOTAL MAN-MINUTES = 9303)

SOLAR	LEVEL 1			LEVEL 2			LEVEL 3			TOTALS		
	Des.	Ins.	Mtn.	Des.	Ins.	Mtn.	Des.	Ins.	Mtn.	Des.	Ins.	Mtn.
TECHNICIAN	185	0	0	215	120	0	1175	240	0	1575	360	0
	185 (2.0%)			335 (3.6%)			1415 (15.2%)			1935 (20.8%)		
MECHANIC	0	30	0	0	0	120	0	0	0	0	30	120
	30 (0.3%)			120 (1.3%)						150 (1.6%)		

FLAT-PLATE - AIR SYSTEM (TOTAL MAN-MINUTES = 10390)

SOLAR	LEVEL 1			LEVEL 2			LEVEL 3			TOTALS		
	Des.	Ins.	Mtn.	Des.	Ins.	Mtn.	Des.	Ins.	Mtn.	Des.	Ins.	Mtn.
TECHNICIAN	185	0	0	215	120	0	1175	240	0	1575	360	0
	185 (1.8%)			335 (3.2%)			1415 (13.6%)			1935 (18.6%)		
MECHANIC	0	30	0	0	0	120	0	0	0	0	30	0
	30 (0.3%)			120 (1.2%)						150 (1.5%)		

training would devote a large portion of training time to conventional skills and a much smaller portion to "solar" skills, such as through a certificate program. An institution training "mechanics" possessing conventional skills would likely offer a program to teach "solar" skills through short courses.

D.2. SOLAR TECHNICIAN TRAINING

A solar technician is a person responsible for the design of a solar energy system. The technician is also responsible for overall system check out and for troubleshooting in case of repair. He is expected to have enough knowledge and skills to perform solar related tasks of relative sophistication.

The educational preparation to enable the solar "technician" to perform the above tasks includes the following:

(1) A high school education
(2) Basic mathematics
(3) Basic physics
(4) Basic computer programming
(5) Basic heat transfer theory
(6) Basic fluid flow theory
(7) Drafting/blueprint reading
(8) Sun/earth relationships and other environmental problems
(9) Basic engineering technology.

The education necessary for a solar "technician" exceeds that of a typical tradesman, and is beyond the high school level. The conventionally trained tradesman in plumbing, sheet metal, or heating, ventilating, and air conditioning can not be easily upgraded to perform the tasks of the solar technician, which amount to approximately 20% of the total time required to produce a solar energy system. The technician's tasks require design skills and thus demand scientific and mathematical knowledge. These persons require education and training which differs from present trade programs. The best way to train these technicians would be through a new, educational program, similar to a two-year vocational training program.

E. MANPOWER AT VARIOUS EDUCATIONAL LEVELS

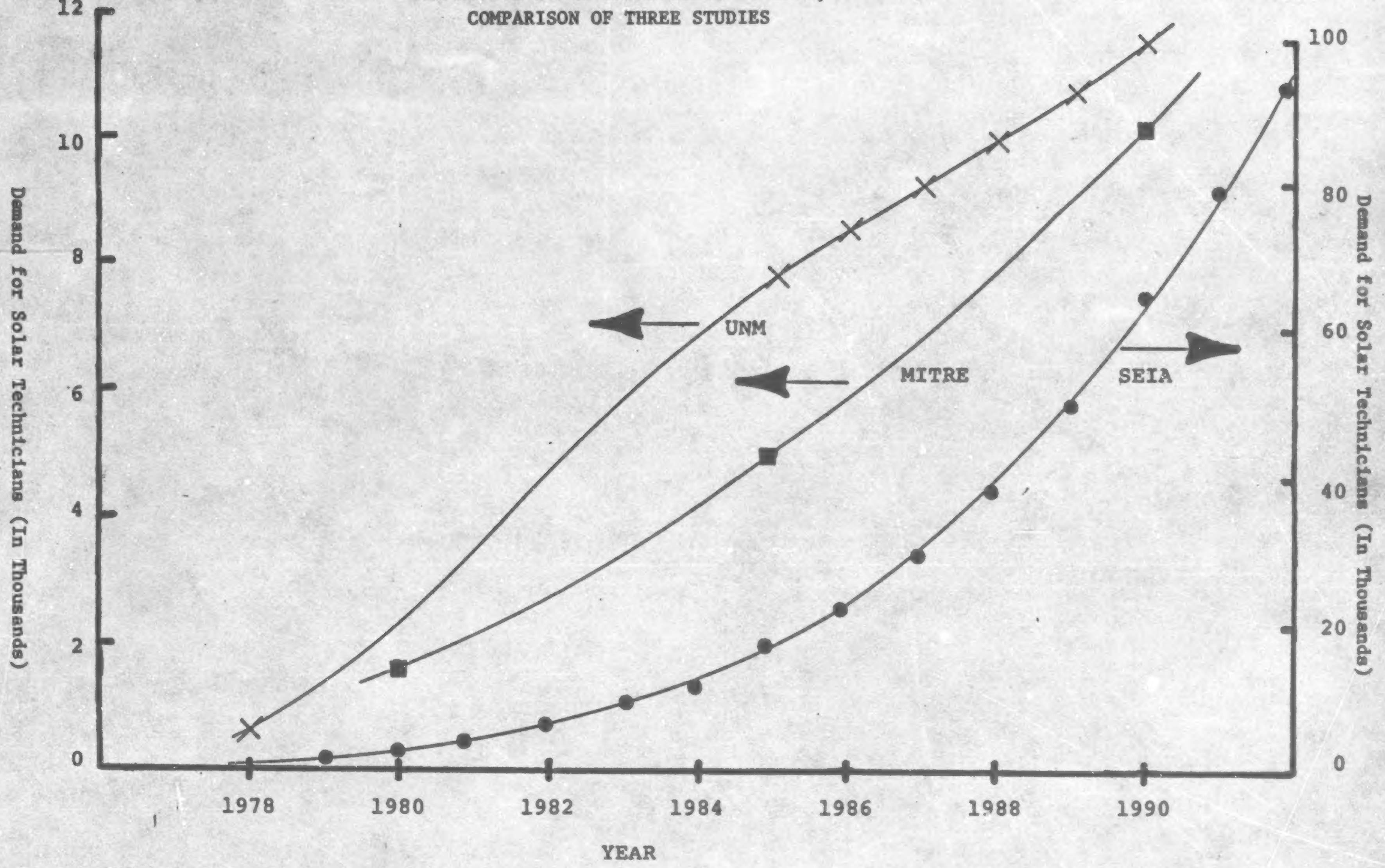
The quantitative manpower demand at various educational levels must be determined to justify the development and implementation of any type of curriculum. The final results of this project should serve as a guideline that clearly establishes the type of curriculum needed to train persons in the solar energy industry. This section combines the results of the section which contain the percentages of total job time computed for both the mechanic and the technician, and the results of the section which contain the total manpower required for the solar energy heating and cooling industry.

E.1. SOLAR TECHNICIAN DEMAND

Approximately 20% of the time required to produce a solar heating system is involved with technician level tasks. Thus, the demand for solar technicians should be one-fifth of the total manpower required for the solar energy industry. In the design, installation, and maintenance of a solar domestic hot water system a technician would be required for approximately 10 hours. For a combined space heating/domestic hot water system approximately 30 hours would be required of a technician. For both new and retrofit installations, the solar technician must devote some of his time to the interfacing of the conventional and solar energy systems. He would also be expected to spend some of this time in a supervisory and administrative capacity.

The regional manpower demand by state for solar technicians based on the UNM study is shown in Figure 24. The technician demand for 16 regions

FIGURE 27 - Page 63
DEMAND FOR SOLAR TECHNICIANS BY YEAR,
COMPARISON OF THREE STUDIES



based on the MITRE report is shown in Figure 25. For SEIA no regional manpower data are available. The overall technician demand is shown in Figure 26 along with the overall demand for each year based on the other two studies.

For comparison purposes, the demand for solar technicians for each year is plotted in Figure 27. Each of the three studies indicates an increase in demand with succeeding years. According to the MITRE study, the demand will rise linearly in small increments. The UNM study predicts that the demand will increase linearly with substantial increases in the years 1980, 1985 and 1990. The demand for solar technicians based on the SEIA study increases exponentially following a conservative beginning.

FIGURE 25.

DEMAND FOR SOLAR TECHNICIANS BY REGION BASED ON MITRE REPORT

REGION	1978	1980	1985	1990
BOSTON	53	108	217	260
WASHINGTON	48	107	304	529
ALBANY	23	50	154	270
LOS ANGELES	135	276	738	1046
CHARLESTON	107	246	786	2060
BISMARK	27	54	126	194
NASHVILLE	116	259	912	2207
FORT WORTH	86	193	787	1763
OMAHA	26	54	176	305
SEATTLE	5	15	33	73
PHOENIX	12	30	84	179
MIAMI	27	58	258	636
MADISON	43	87	228	362
CHICAGO	14	24	51	68
CAPE HATTERAS	8	18	67	151
ATLANTA	2	5	32	47
TOTAL	733	1585	4956	10153

FIGURE 26.

OVERALL TECHNICIAN DEMAND

YEAR	UNIVERSITY OF NEW MEXICO	SEIA	MITRE
1978	700	254	733
1979	1096	761	-
1980	3443	1677	1585
1981	3643	3639	-
1982	4465	6184	-
1983	4616	8783	-
1984	5429	11417	-
1985	7907	16465	4956
1986	8559	22386	-
1987	9269	29740	-
1988	10007	38793	-
1989	10853	50225	-
1990	11595	64823	10153
1991	-	79731	-
1992	-	93614	-

E.2. SOLAR TRADESMAN/MECHANIC DEMAND

Approximately 2% of the time required to produce a solar heating system is involved with "solar" tasks that are assignable to the solar mechanic level. It seems impractical to assume that a person would devote 100% of his time at this level of performance as a solar mechanic. Rather he would be expected to devote the majority of his time to conventional tasks, but would also be capable of performing the "solar" tasks when needed. Eighty percent of the solar work force will be comprised of "mechanics".

SOLAR TRADESMAN/MECHANIC DEMAND

A. SKILLS REQUIREMENTS

This section deals with both the time required for design, installation, and maintenance per solar system and the skills necessary to perform the required tasks.

A. 1 MANHOURS PER SOLAR SYSTEM

Four inputs were used in determining the "typical" hot water and space heating/hot water systems:

1. A contractor survey.
2. A manufacturer/distributor/dealer survey.
3. Experts' evaluation.
4. A task inventory.

Each of the above is described in detail in Chapters II and III. The average manpower requirements per solar system are presented in the Figure 28.

FIGURE 28.

MANHOUR REQUIREMENTS FOR "TYPICAL" SOLAR SYSTEMS

	Hot Water System	Space Heating/ Hot Water System
Design	10	30
Installation	40	135
Maintenance (yearly)	2	10
Total	52 manhours	165 manhours

Solar Tasks and Workers

Using the Task Analysis (Appendix L), the "solar" tasks were identified. These solar tasks were then divided into two categories.

Solar Mechanic

A solar mechanic is a person who is expected to perform basic or entry level tasks of installation and routine maintenance on solar systems. Only two percent of the total manhours required of the mechanic on a solar system must be devoted to tasks identified as "solar" tasks. The "solar" tasks to be performed by the solar "mechanic" are:

1. Mount each collector.
2. Check normal positions of motorized valves and dampers.
3. Monitor flow rates and temperature differentials to test system operation.

The educational preparation for the solar "mechanic" to be able to learn these "solar" tasks is as follows:

1. A high school education.
2. Experience primarily in plumbing (for liquid systems) or in sheet metal (for air systems).

Thus, the educational background for the solar "mechanic" is the education of the practicing plumber or sheet metal tradesman with solar application.

Solar Technician

The solar technician is responsible for the design phase and overall system check-out. Specifically, his "solar" duties and tasks are:

1. Calculate hot water load.
2. Choose collector type.
3. Calculate solar gain on unit area basis.
4. Determine maximum available collector area.
5. Determine optimum collector area.
6. Design fluid flow system.
7. Check out the system powered components.

8. Calibrate and test solar temperature differential controls.

9. Test system operational modes.

The educational requirements for the solar "technician" to be able to perform the above tasks include the following:

1. A high school education
2. Knowledge of basic mathematics
3. Basic Physics
4. Basic computer programming
5. Basic heat transfer theory
6. Basic fluid flow theory
7. Drafting/blueprint reading
8. Astronomy (sun/earth relationship)
9. Basic engineering.

Thus, the education necessary for a solar "technician" exceeds that of a typical tradesman, and is beyond the high school level.

A.2. CONVENTIONAL TRADESMEN TASKS

HVAC journeyman skills are needed for 5% to 6% of the time required to design, install, and maintain a solar system, attributable almost entirely to the design stage. Plumbing skills for a liquid system are required approximately 55% of the time, and this same percentage applies to sheet metal skills for an air system. Lastly, electrician skills are required about 4% to 5% of the time, carpentry about 1%, and general skills about 10% of the time.

B. MANPOWER REQUIREMENTS

The total manpower required for the solar industry as well as the manpower to be trained at various educational levels are described in this section. The details on total manpower requirements are discussed in Chapter II. Details on various educational requirements are discussed in Chapter III. The yearly increment in manpower demand and rate of supply are discussed in this section.

B. 1 TOTAL MANPOWER

The University of New Mexico, MITRE, and SEIA studies were used to determine the demand for solar equipment. Based on each forecast, the projections of manpower demand are calculated and listed in Figures 14 through 19. For comparison purposes these projections are plotted on a yearly basis in Figure 20. The forecast based on the SEIA study gives the highest figures, amounting to approximately 80,000 practicing solar workers in the field in 1985. The forecast based on the University of New Mexico study predicts that nearly 40,000 people will be working in the field in the year 1985. The most conservative forecast, based on the MITRE study, predicts that 25,000 people will be working in the field in the same year. These numbers are for the residential sector alone. There may be a substantial demand in other sectors as well.

By 1990 this demand is expected to increase to a minimum of 50,000 workers in the field, according to the MITRE and UNM studies, and to 325,000 people according to the SEIA study.

B. 2 REGIONAL DEMAND

The UNM study which predicts regional demands indicates that the northeastern and north central parts of the country will require the largest portion of manpower by the year 1985. The states of Pennsylvania, New York, New Jersey, Massachusetts, Michigan, Minnesota, and Connecticut head the demand list. Other states with high demand for solar manpower are California, Florida, Texas, Virginia, and North Carolina. By 1990 high demand for solar workers is found in Illinois, Georgia, Alabama, Iowa, and Ohio as well.

Based on the MITRE study, in 1985 the regions represented by Washington, Miami, Fort Worth, Nashville, Charleston, and Los Angeles will have substantial demand for solar manpower, and by 1990 the regions represented by Madison, Omaha, and Boston will be added. A comparison of these regional demands shows that these two studies agree on the regions of high manpower demand. The SEIA study does not list the demand for solar equipment by region.

B. 3 SOLAR TECHNICIANS

The demand for solar technicians comprises one-fifth of the total manpower requirement. Thus, the demand for solar technicians in 1985 by the solar industry is expected to be at least 5000 according to forecasts based on the MITRE report. This demand grows to nearly 10,000 by 1990. Based on the UNM and SEIA studies, the demand is 8000 and 22,000 solar technicians, respectively, in 1985, and grows to 12,000 and 65,000 in 1990. The geographical regions with high demand for solar technicians are the same as those mentioned above.

C. TRAINING PROGRAMS

It is noted in Chapter III that a minimum of new training programs will be required to train solar mechanics. Most of these should be programs concentrating on HVAC and plumbing training with 2% solar skill instruction. However, solar technician training will require a new program. Typically, community colleges train technicians and tradesmen with two-year Associate Degree programs and supply the manpower for various industries. Assuming that solar technicians will be trained by community colleges, it is important to know the number of community colleges that should be engaged in training these individuals to satisfy the expected demand. To determine this number, the yearly increment in manpower demand was calculated using forecasts based on UNM. These data are plotted in Figure 29. Nearly 4000 workers must be trained properly every year to fulfill the increment in demand up to 1985. This steady rate must be maintained to ensure the continued growth of the solar field. Of these 4000 people, at least 800 must be trained at the solar technician level every year. A community college on the average could train 50 solar technicians a year. Thus, 40 community colleges should be engaged in training these solar technicians by 1985.

In the years from 1985 to 1990, the steady rate of supply must be increased to nearly 6200 total workers and at least 1200 solar technicians, implying that another 40 shools will undertake the responsibility of training these technicians.

Based on SEIA study, the yearly increment in manpower demand is calculated and is plotted in Figure 30. The average rate of trained manpower production must be 9300 per year up to 1985, implying that nearly 40 schools should be engaged in training nearly 2000 solar technicians. Between 1985 and 1990, this average rate of production of solar technician increases to 9000 per year. This would require that another 140 schools begin training solar technicians during this time period.

For years 1991 and 1992 the rate of production of solar technicians increases to nearly 14,000 every year requiring 120 more schools for training.

FIGURE 29. YEARLY INCREMENT IN DEMAND VERSUS YEAR
FOR SOLAR TECHNICIANS
BASED ON THE UNIVERSITY OF NEW MEXICO STUDY

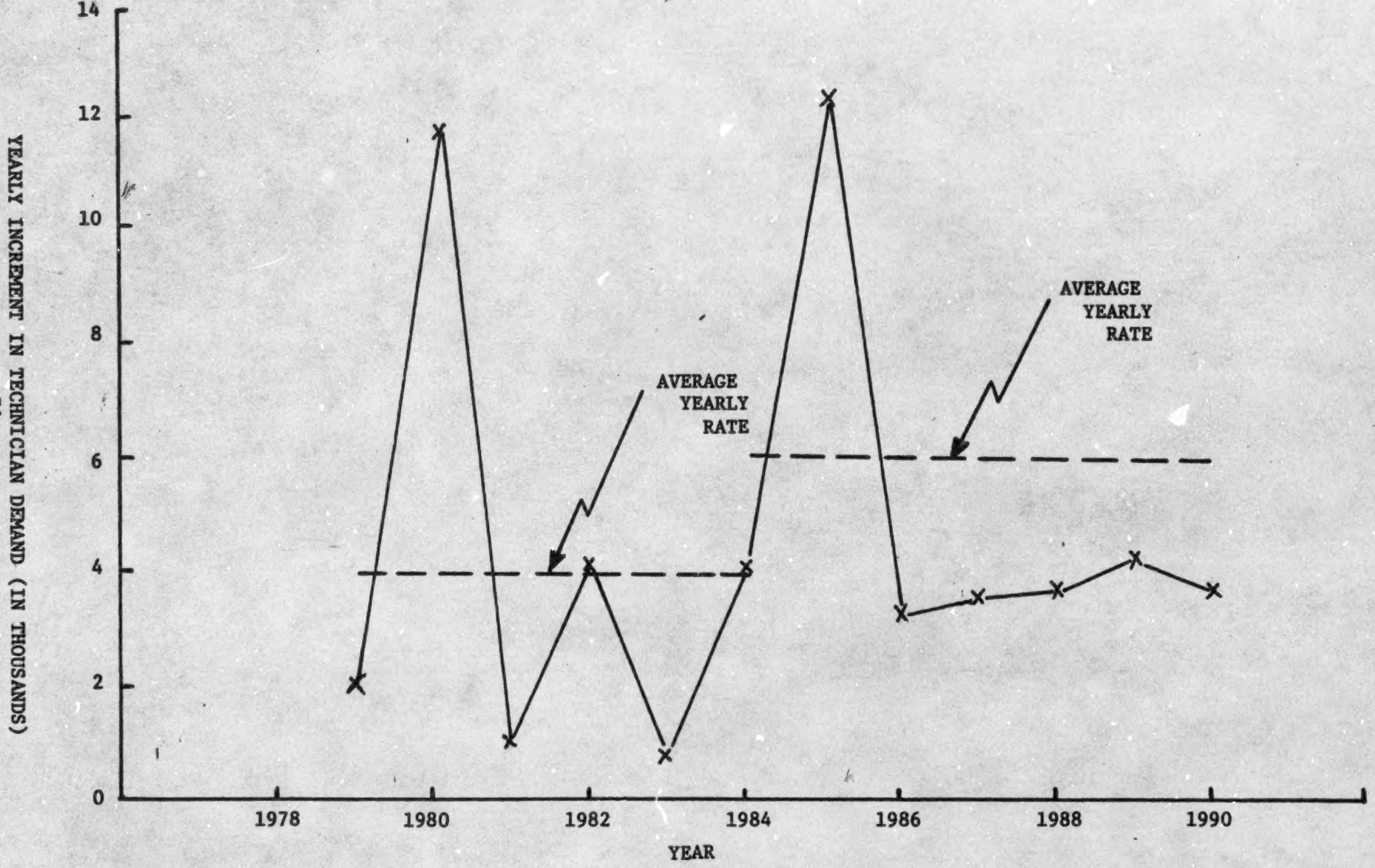
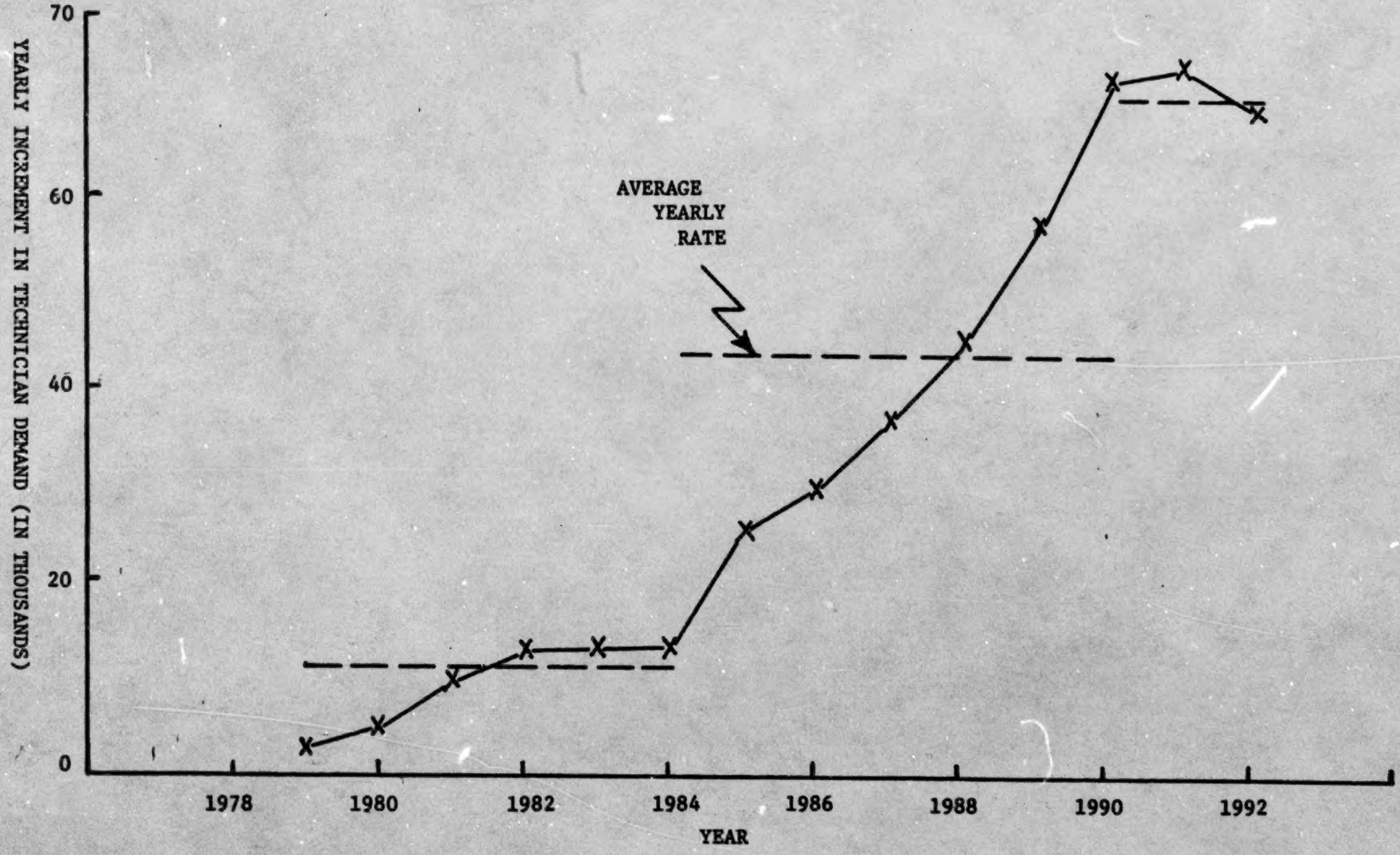


FIGURE 30. YEARLY INCREMENT IN DEMAND VERSUS YEAR FOR SOLAR TECHNICIANS BASED ON THE SEIA STUDY



V. CONCLUSIONS AND RECOMMENDATIONS

If government and industry are to be successful in stimulating commercial use of solar energy, they must concurrently provide for the development of a manpower resource with the knowledge and skills to install and maintain solar systems. Due to the costs of developing and implementing a new curriculum, as well as substantial investment required from those who undertake the training, there should be a well-founded expectation that there will be a clear demand for the training and for the graduates of the training program. The purpose of this research project has been to identify the quantitative and qualitative needs of a trained manpower pool for the solar energy industry as it relates to the residential market in the United States.

A. QUALITATIVE FACTORS OF SOLAR WORKER TRAINING

There are two major conclusions concerning the qualitative aspects of solar worker training.

1. Solar workers are categorized into two distinct classes: a) technicians, and b) mechanics.

2. There is a need for solar workers to be trained in conventional heating, ventilating, and air conditioning (HVAC) skills and plumbing skills, as well as solar skills.

A. 1 SOLAR TECHNICIANS

The solar technician has knowledge and skills specific to solar system design, installation, and diagnostic troubleshooting. Solar technician training will be a two year program similar to training for HVAC technicians. The need for a solar technician training program is immediate, but varies by region and time of implementation.

A. 2 SOLAR MECHANICS

The solar mechanic is defined as a tradesman who has knowledge of solar systems. There is a need for an educational training program for workers in the solar mechanic class if the individual does not have previous knowledge and training in HVAC and plumbing. Today, solar mechanic training for mechanics with HVAC and plumbing backgrounds is being done either by the solar industry manufacturers, distributors, and dealers, or through additions or options to conventional technical-vocational programs and continuing education classes. This trend will probably continue in the future. For those with no previous training in these areas, solar options must be added to curricula in conventional HVAC, plumbing, and related vocational programs at educational institutions.

A. 3 TRAINING REQUIRED

In analyzing the tasks for design, installation, and maintenance of solar systems, it was discovered that the solar tasks accounted for approximately 22% of the total task time. The majority of installation skills are plumbing-trade related for liquid-type solar systems and the majority of installation skills are sheet metal-trade related for air-type solar systems. The solar system design skills are divided between conventional HVAC skills, approximately 25% of design time, and those skills specifically related to solar, approximately 75%.

The earnings of the solar technician should be comparable to that of trained plumbers and HVAC tradesmen. The earnings of the solar mechanic should be comparable to that of trained HVAC or plumber journeymen.

B. THE QUANTITATIVE DEMAND FOR SKILLED SOLAR WORKERS

A substantial demand for trained, skilled solar workers will develop concurrently with the demand for solar equipment. The manpower forecast is a direct function of the equipment market studies which show the following general pattern of development.

1. There will be at least 2.4 million solar units installed by 1985.
2. There must be a minimum of 25,000 skilled workers in the solar field by 1985.
3. One-fifth, or 5000, of the solar workers must be trained at the technician level.

B. 1 SPACE HEATING

Demand for solar space heating will increase in the Canadian border states, in the extreme northeast, and north-central parts of the nation bewteen the present and 1980. Between 1980 and 1985, the middle belt states show increasing demand. As expected, far fewer space heating systems are forecast for the sun belt states.

B. 2 WATER HEATING

Demand for solar water heating (without space heating) is geographically scattered. The trend for implementation seems to depend directly on insolation and electric rates.

C. SUPPLY OF SOLAR SKILLED WORKERS

Eighty technician training schools with solar programs will be needed, each graduating 50 technicians per year, between the present and 1985. To fill the yearly demand for technicians between 1985 and 1990, 40 additional schools will be required. The regional development of these schools should follow the regional demand for installed systems. The lead time required for instituting new programs in vocational and technical schools is generally about 3 years. Implementation of solar training programs in the regions indicated in this report must be started immediately if the 1985 demands for skilled personnel are to be met.

D. RECOMMENDATIONS

Recommend:

1. That the solar mechanic training programs now being undertaken by solar manufacturers, distributors, and some trade unions be continued. This training should also be conducted through short courses, continuing education programs, and certificate programs.

2. That the development of solar technician training programs be begun immediately.

3. That the basic technician training program contain the flexibility to accommodate local/regional variations and future developments in the solar industry.

APPENDICES

A. National Advisory Committee

B. Consultants for Task Analysis

C. Solar Energy Equipment Manufacturers

D. References

E. Solar System Design and Installation Time

F. Solar Feasibility Maps, University of Mexico Study

G. Existing and Projected Housing Stock

H. Contractors' Survey, Statistical Analysis

I. Personal Interviews, Solar Manufacturer/Distributor/Dealer

J. Contractors' Survey Form

K. Task Inventory Form

L. Task Analysis

M. Task Analysis, Solar Tasks

N. Contractors' Survey, Comments

APPENDIX A

NATIONAL ADVISORY COMMITTEE

The progress of this project has been continually monitored by an Advisory Committee composed of experts in the fields of solar energy and education. They have provided input on the state of the solar field, helped formulate project assumptions, read conclusions, and provided overall guidance and direction for research on this project.

COMMITTEE MEMBER	MAILING ADDRESS
Mr. Sheldon H. Butt Mr. Butt is President of the Solar Energy Industries Association and was recently voted "Solar Man of the Year" by that organization.	Mr. Sheldon H. Butt Olin Brass Company, Inc. East Alton, Illinois 62024
Dr. John David Gavenda Dr. Gavenda is a Professor of Physics and Education and has been involved for many years with national science curriculum development projects.	Dr. John David Gavenda Department of Physics University of Texas at Austin Austin, Texas 78712 512/471-3201
Dr. David Herrington Dr. Herrington is Director for Training for Sheet Metal and Air Conditioning Contractors National Association and is actively involved in trade education.	Dr. David Herrington AA for Tech. and Educational Programs 1900 L Street, NW, Suite 405 Washington, D. C. 202/833-9543
Dr. Milton E. Larson For the last quarter of a century Dr. Larson has been engaged in educational work. Technical Education and Trade and Industrial Education have been the focus of his activity.	Dr. Milton E. Larson Department of Vocational Education Colorado State University Ft. Collins, Colorado 80523 303/491-6857
Dr. Michael Z. Lowenstein Dr. Lowenstein has been a Professor of Chemistry and Energy Education for the last thirteen years. He has recently specilized in solar education and is on loan to Navarro College to direct a solar curriculum development project.	Dr. Michael Z. Lowenstein, Director Solar Energy Division Navarro College P. O. Box 1170 Corsicana, Texas 75110 214/874-6501

Mr. J. G. "Glenn" Meredeith

Mr. Meredeith is President of Ham-Mer Consulting Engineers, Inc., a company that specializes in Industrial Energy Conservation. He has been active in the design of numerous industrial solar energy installations.

Mr. J. G. "Glenn" Meredeith, President
Ham-Mer Consulting Engineers, Inc.
5000 E. Ben White Blvd., Suite 301
Austin, Texas 78741

Mr. Les Keliher

Mr. Keliher is a Vice President of Northrup, Inc., a company that is extremely active in the manufacturer of concentrating solar collectors.

Mr. Les Keliher
Northrup, Inc.
302 Nichols Drive
Hutchins, Texas 75141
214/225-4291

Mr. Dwight Rathmell

Mr. Rathmell has served the project as a representative of organized labor.

Mr. Dwight Rathmell
Executive Secretary
Dallas Bldg. & Construction Trades Council
7940 Northaven
Dallas, Texas 75230
214/691-2617

Mr. P. Richard Rittelmann

Mr. Rittelmann is Pricipal - Burt Hill & Associates, Architects. He has been the Project Architect for more than ten large solar energy installations and has numerous publications in the area of solar heating and cooling technology.

Mr. P. Richard Rittelmann, AIA
Burt, Hill Associates
610 Melon Bank Bldg.
Butler, Pennsylvania 16001
412/285-4761

Mr. George Smith

Mr. Smith is a contractor who has pioneered solar energy installations in the State of Texas. He conducts solar short courses for contractors.

Mr. George Smith, President
George Smith, Inc.
5011 Duval
Austin, Texas 78751

Dr. R. I. Vachon

Dr. Vachon's a Professor of Mechanical Engineering and has been involved in several national solar demonstration projects. He has published widely in the area of Thermal Science.

Dr. R. I. Vachon
Professor of Mechanical Engineering
Auburn University
Auburn, Alabama 36830
205/826-4574

Mr. Paul Wengert

Mr. Wengert is Senior Operations and Research Analyst for Owens-illinois. He has been extremely active in the area of forcasting the financial inpact of solar energy systems.

Mr. Paul Wengert
Corporate Planning
Owens-Illinois
P. O. Box 7035
Toledo, Ohio 43666
419/242-6543

Dr. John Yellott

Dr. Yellott is a Professor of Architecture and is considered to be one of the country's "Solar Pioneers", having been active in the solar energy field for more than thirty years.

Dr. John I. Yellott
College of Architecture
Arizona State University
Tempe, Arizona 85281

APPENDIX B

CONSULTANTS FOR TASK ANALYSIS

A committee of professionals was gathered to develop the task analysis. This appendix lists the committee members with their addresses and a brief statement of their qualifications.

COMMITTEE MEMBER	MAILING ADDRESS
Mr. Tom L. Hindes Mr. Hindes has been active for many years in the areas of occupational task analysis and curriculum development.	Mr. Tom L. Hindes, Director Instructional Materials Laboratory Trade & Industrial Education The Ohio State University 1885 Neil Avenue Columbus, Ohio 43210
Mr. William C. Matlock Mr. Matlock has an HVAC background. His company has installed fifty solar systems and he is active in the design of solar powered irrigation systems.	Mr. William C. Matlock, President Sunpower Systems Corporation 2123 S. Priest St., #216 Tempe, Arizona 85282
Mr. Damon P. Nolan Mr. Nolan is President of Solar Age Systems and has completed several solar heating systems in the North Texas Area.	Mr. Damon P. Nolan, President Solar Age Systems 217 E. Hickory Street Denton, Texas 76201
Mr. David Rozell Mr. Rozell has designed and teaches courses on solar technology. He also has field experience with solar systems.	Mr. David Rozell Solar Technician Training Project Office of the State Architect Dept. of General Services 1322 "O" Street Sacramento, California 95814
Mr. David Springer Mr. Springer has designed and installed a large number of solar systems.	Mr. David Springer Natural Heating Systems 2417 Front Street West Sacramento, California 95616

APPENDIX C

SOLAR ENERGY EQUIPMENT MANUFACTURERS

This appendix contains a list of manufacturers who are engaged in the production of solar equipment or in some aspect of solar research. This list was developed from advertisements in solar and engineering journals, from government publications, and from personal knowledge of project personnel. Each manufacturer was contacted by letter.

The manufacturers are listed once along with their products or research areas, and again with mailing addresses and phone numbers.

COMPANY	PRODUCT CODES
A. O. Smith Corp.	CS,DHW
Asarco	DI
Acorn Structures	DHN,SH
Acurex Corp.	CC,DHW,IHW
Advance Cooler Mfg.	DHW
Albuquerque Western Industries	CC,DHW
Alcan Aluminum Corp.	DHW
Alcoa	AP,CA,CF,PH
Allied Chemical	PC
Alpha Designs, Inc.	PG
Alten Assoc., Inc.	CF,DHW,SH
Alternative Systems	DI
American Appliance	CF,DHW
American Heliothermal	CF,DWH
American Solar Heat Corp.	CF,DHW,ST
American Solar Power Inc.	CF,DHW
American Sun Industries	DHW
Ametek, Inc.	CA,CF
Aqua Solar, Inc.	PH
Aromore Textured Metals	AP
Arkla Industries, Inc.	AC
Automated Building Components, Inc.	AP
Aztel Solar Co.	CS,DHW,IC
Barber-Nichols Engineering	AC
Bausch & Lomb	CO
Bell & Gossett	CS
Bell County Supply	DI
Berry Solar Products	CA
Beutels Solar Heating	DI
Bray Oil Co.	F
Burke Ind., Inc.	PH
Burnham Corp.	P
CBM Manufacturing Inc.	CF
LSI Solar Systems	CF,DHW
Calmac Mfg.	CC,DHW,PH
Carrier	HP
Catel Manufacturing, Inc.	PH
Chamberlain Mfg. Co.	CF
Champion Home Builders	CF,SH
Chemical Processors, Inc.	CF,DHW
Clary Corp.	IC,IM
Coating Laboratories	CA
Cole Solar Systems	CF,DHW
Columbia Solar Energy Div.	CF,DHW
Communications Satellite Corp.	PC
Conserdyne Corp.	DHW
Contemporary Systems Inc.	CF,DHW,SH
Corning Glass Works	CE
Crimsco, Inc.	CF,SH

COMPANY	PRODUCT CODES
Croton Chemical Co.	CT
Crow-Sterner Assoc.	DI
Crystal Systems, Inc.	PC
Cushing Instruments	IM
Dalton Tanks and Supply Inc.	ST
Daystar Corp.	CF,DHW,SH
L.M. Dearing Assoc., Inc.	PH
Del Sol Control Corp.	IC
Delevan Electronics, Inc.	IC
Delta-T	IC
Desert Sunshine Exposure Tests, Inc.	TF
Devices and Services Co.	IM
Diy-Sol, Inc.	CF,DHW,SH
Dow Chemical	F
Dow Corning	CE,F,P,PC
Dynaire	DHW
E&K Service Co.	CF
E-Systems	CF
Eaton Corp.	IC
Ecotechnology	CF
Ecotope Group	DHW
Edwards Engineering Corp.	CS,DHW
Elcam, Inc.	DHW
Energy Applications, Inc.	IC
Energy Converters, Inc.	CF,DHW,ST
Energy Dynamics Corp.	HP
Energy Engineering, Inc.	ST
Energy Systems, Inc.	CF
Enersol Co.	DI
Enertech Corp.	DI
Eppley Laboratory, Inc.	IM
Erie Mfg. Co.	CS
Fafco, Inc.	CF,DHW,SH,PH
Falbel Corp.	CC,DHW,PH
Flagala Corp.	CF
Florida Solar Energy Center	TF
Ford Products Corp.	ST
Friedrich	AC
Future Systems, Inc,	CF,SH
General Atomic Co.	CC,IHW,PG
General Electric Co.	CE,DHW,HP,SH
General Energy Devices, Inc.	CF,CS,DHW,PH,SH
Gould, Inc.	CS
Grundfos Pump Co.	CS
Halstead & Mitchell	CF,DHW,HP,SH
Hamilton Research	DHW
Hawthorne Industries	IC
Helio Associates	CF,DHW
Helios Corp.	CF,DHW,SH
Heliotherm, Inc.	CF

COMPANY	PRODUCT CODES
Heliothermics	CF,DHW,SH
Heliotrope General	DHW,IC,PH
Hexcel Corp.	CC
Hi-Tech Inc.	CS
Highland Plating, Inc.	CA
Hollingsworth & Jackson	DI
Honeywell, Inc.	CF,DHW,IC,SH
Hubbell	ST
I.B.M.	PC
IMC Instruments, Inc.	IM
ITT Fluid Handling Div.	CS
Ilse Engineering	CF
Independent Energy, Inc.	IC
Independent Living Inc.	DHW
Industrial Systems, Inc.	DI
International Environment Corp.	CF,DHW
International Rectifier	PC
International Solarthermics	SH
Intertechnology Corp.	AC,CF,DHW,SH
Jackson Mfg. Co.	CF,DHW
Jacobs-Del Solar Systems	CC
Johnson Controls	IC
KTA Corp.	CE,SH
Kalwall Corp.	CF,CS,DHW,IC,P,SH
Kastek Corp.	PH
Kennecott Copper Corp.	AP,CF
Largo Solar Systems	CF,DHW,PH,ST
Lennox Industries, Inc.	CF,DHW,HP,SH
Libby-Owens-Ford	CF
Lof Brothers Solar Appliances	PH
MND Inc.	IM
Mann-Russell Electronics, Inc.	IC
March Mfg. Co.	CS
Mar-Scot Solar Pac Systems	DHW
Martin Processing, Inc.	CO
Matrix, Inc.	IM
McDonnell Douglas	PG
Mid-West Technology	AP
Mobil-Tyco	PC
Mor-Flo Industries	DHW
Motorola, Inc.	PC
NRG, Ltd.	CF
National Energy Corp.	DHW
National Plastics, Inc.	CF,PH
National Solar Corp.	CF
Natural Energy Systems	CF,DHW,PH,SH
Natural Power, Inc.	IM
Navajo Air Equipment	DI
New Jersey Aluminum, Co.	CS
Northrup, Inc.	CC,DHW,SH,PH
O.E.P. Products	CF,DHW

COMPANY	PRODUCT CODES
Olin Brass, Inc.	AP
Olympic Plating Ind., Inc.	CA
Optical Coating Lab, Inc.	CA,CO
Opto Technology, Inc.	PC
Oriel Corp.	IM
Owens Enterprises, Inc.	CC
Owens-Illinois, Inc.	CE
PPG Ind., Inc.	CA,CF
Pacific Sun, Inc.	DHW
Payne, Inc.	CF
People/Space Co.	CF
R-M Products	CF,CS,DHW,PH
Ranco	IC
Raypak	CF,DHW,PH
Refrigeration Research	CS,CF,IC,DHW
Research Products Corp.	SH
Resource Technology Corp.	F
Revere Copper and Brass, Inc.	CF,DHW,PH
Reynolds Metals Co.	CF
Rho-Sigma	IC
Roark, C.F., Welding & Engineering Co.	DHW,PH,SH
Robertshaw Controls Co.	IC
Rockwell International	ST
SES, Inc.	PC
S.W. Enertech, Inc.	CF
Scientific-Atlanta	AC,CF,CC,CS,DHW,SH,ST
Scientifico	CF
SEMCO	CF
Sennergetics	CA,CF,CS,DHW,P,PH,SH,ST
Sensor Technology, Inc.	PC
Shaw Pump, Inc.	CS
Sheldahl Co.	CC
Sigma Research, Inc.	CF,SH
Siltec Corp.	PC
Simons Solar Environmental Systems, Inc.	DHW
Skytherm Processes Engineering	P
Sol-Aire	DHW,PH
Solar, Inc.	CF,ST
Solar Age Systems	SH
Solar-Aire	CF,SH
Solar American	CF,DHW
Solar Applications, Inc.	CF,DHW
Solar Comfort Systems, Div.	DHW
Solar Control Corp.	IC,SH
Solar Controllar Inc.	IC
Solar Corp. of America	DHW
Solar Development, Inc.	CF,DHW,PH,SH
Solar Dynamics, Inc.	CF,DHW,PH
Solar Electric International, Inc.	HP
Solar Energy Products, Inc.	DHW

COMPANY	PRODUCT CODES
Solar Energy Resources Corp.	DHW,PH
Solar Energy Systems	CF
Solar Energy Systems, Inc.	DHW,ST
Solar Enterprises, Inc.	CF,DHW
Solar Industries, Inc.	CE
Solar Innovations	CF,DHW,SH,ST
Solar Kinetics, Inc.	CC
Solar Kinetics, Corp.	CC,DHW,PH
Solar King,Inc.	AC,DHW,PH,SH
Solar Physics Corp.	PG
Solar Power Corp.	PC
Solar Products	CF
Solar Research Systems	PH
Solar Room Co.	P
Solar Sun	CF,DHW,SH
Solar Systems, Inc. (WI)	DHW,SH
Solar Systems, Inc. (TX)	CF
Solar Systems Sales	ST
Solar Thermics Enterprises	SH
Solar Utilities Co.	CF
Solarator	DHW
Solaray, Inc.	CF,DHW
Solarcoa	CF,DHW,PH
Solarex Corp.	PC
Solargenics, Inc.	CF,DHW
Solargizer Corp.	DHW,PH
Solaron	AC,CF,DHW,SH
Solarponics	DI
Solcan, Ltd.	SH
Solec International, Inc.	PC
Solergy, Inc.	CC
Sollos, Inc.	PC
Soltherm Corp.	CF,DHW
Soltrax Corp.	CF,DHW,SH
Solus, Inc.	CF,DHW,HP,SH
Southeastern Solar Systems	CF,DHW,SH
Southern Lighting Mfg. Co.	CF,DHW
Spectran/Instruments	IM
Spectrolab, Inc.	PC
State Industries	CF,DHW
Stolle Corp.	CF
Sun Power Systems Ltd.	CF,DHW
Sun Stone	CF,DHW,SH
Sun Systems, Inc.	DHW,SH
Sundu Co.	PH
Sunearth, Inc.	CF,DHW
Suneargy Power Ltd.	DHW
Sunglaze, Inc.	CF
Sunpower Systems Corp.	CC
Sunstream	CF,DHW,SH

COMPANY	PRODUCT CODES
Suntap, Inc.	PC
Sunworks	CF,DHW,F,SH
Swedcast Corp.	CS
Technology Applications Laboratory	IC
Texas Electronics, Inc.	IM
Texas Solar, Inc.	DI
Thermon Manufacturing	AP,CS
Thomason Solar Homes, Inc.	AC,DHW,SH
3-M Company	CA,CO
Tranter	AP,CF
Turbonics, Inc.	SH
Tuthill Pump Company	CS
U.S. Solar Pillow	DHW,PH
Unit Electric Control, Inc.	CF,DHW
United Technologies	HP
Varian	PC
Vermon Solar Group, Inc.	DI
Vinyl Fab Industries	PH
Westinghouse Electric Corp.	HP
Wilcon Corp.	CF,DHW,IM,ST
Willey Corp.	IC,IM
Wiltronics	IC,IM
Wormser Scientific Corp.	CF,SH
Ying Mfg. Corp.	DHW
York	HP
Zomeworks corp.	P

PRODUCT CODES

AC	Air Conditioning - General
AP	Absorber Plates
CA	Absorber Plate Coatings
CC	Concentrating Collectors
CE	Evacuated Tube Collectors
CF	Flat Plate Collectors
CO	Optical Coatings
CS	System Components
DHW	Domestic Hot Water Systems
DI	Distributor
F	Collector Fluids
HP	Solar-Assisted Heat Pumps
IC	Control Instruments
IHW	Industrial Hot Water
IM	Monitoring Instruments
P	Passive Solar Systems
PC	Photovoltaic Cells
PH	Pool Heating
PG	Power Generation
SH	Space Heating
ST	Storage Components
TF	Collector Testing Firm

LISTING OF SOLAR AND SOLAR RELATED FIRMS

A. O. Smith Corp.
P. O. Box 28
Kankakee, IL 60901

ASARCO
120 Broadway
New York, NY 10005

Acorn Structures, Inc.
Box 250
Concord, MA 01742
(617) 369-4111

Acurex Corp.
Aerotherm Division
485 Clyde Ave.
Mountainview, CA 94042
(415) 964-3200

Advance Cooler Mfg. Corp.
P. O. Box 287
Clifton Park, NY 12065

Albuquerque Western Industries, Inc.
612 Commanche N.E.
Albuquerque, NM 87107
(505) 344-7224

Alcan Aluminum Corp.
100 Erie View Plaza
Cleveland, OH 44110
(216) 523-6800

Alcoa
1501 Alcoa Building
Pittsburgh, PA 15219
(412) 553-2748

Allied Chemical
P. O. Box 1021R
Morristown, NJ 07960

Alpha Designs Inc.
1014 Vine St.
Suite 2230, Kroger Building
Cincinnati, OH 45202
(513) 621-1243

Alten Assc., Inc.
2594 Leghorn St.
Mountanview, CA 94043
(415) 969-6474

Alternative Systems
Main St.
Conway, NH 03818
(603) 447-5266

American Appliance Mfg. Corp.
2341 Michigan Ave.
Santa Monica, CA 90404
(213) 829-1755 or (213) 870-8541

American Heliothermal Corp.
3515 S. Tamarac
Suite 360
Denver, CO 80237
(303) 778-0650

American Solar Heat Corp.
Seven National Place
Danburry, CT 06810
(203) 792-0077

American Solar Power, Inc.
5018 West Grace St.
Tampa, FL 33607
(813) 254-4461

American Sun Industries
P. O. Box 263
Newbury Park, CA 91320
(805) 498-9700

SOLAR AND SOLAR RELATED FIRMS (continued)

Ametek, Inc.
One Spring Ave.
Hatfield, PA 19440
(215) 248-4600

Aqua Solar, Inc.
1234 Zacchini Ave.
Sarasota, FL 33577
(813) 366-7080

Ardmore Textured Metals
P. O. Box 327
Woodbridge Ave. at Main St.
Edison, NJ
(201) 549-3800

Arkla Industries Inc.
P. O. Box 534
Evansville, IN 47704
(812) 424-3331

Automated Building Components, Inc.
7525 Northwest 37th Ave.
P. O. Box 2037 AMF
Miami, FL 33159

Aztec Solar Co.
P. O. Box 272
Maitland, FL 32751
(305) 628-5004

Barber-Nichols Engr. Co.
6325 West 55th Ave.
Arvada, CO 80002

Bausch & Lomb
Vacuum Coating Division
1400 North Goodman St.
Rochester, NY 14602
(716) 338-6671

Bell & Gossett
8200 N. Austin Ave.
Morton Grove, IL

Bell County Supply
P. O. Box 2409
Harker Heights, TX 76541
(817) 699-2590

Berry Solar Products
P. O. Box 327
Edison, NJ 08817
(201) 549-3800

Beutels Solar Heating
7161 W. 74th St.
Miami, FL 33166
(305) 885-0122

Bray Oil Comp.
1925 North Marianna Ave.
Los Angeles, CA 90032
(213) 268-6171

Burke Ind., Inc.
2250 S. 10th St.
San Jose, CA 95112
(408) 297-3500

Burnham Corp.
P. O. Box 1079
Lancaster, PA 17604
(717) 397-4701

C.B.M. Manufacturing Inc.
621 Northwest 6th Ave.
Ft. Lauderdale, FL 33311
(305) 463-5810

SOLAR AND SOLAR RELATED FIRMS (continued)

CSI Solar Systems Division
12400 49th St.
Clearwater, FL 33520
(813) 577-4228

Calmac Mfg. Corp.
150 S. Van Brunt St.
Box 710
Englewood, NJ 07631
(201) 569-0420

Carrier
Carrier Parkway
Syracuse, NY 13201
(315) 463-8411

Catel Manufacturing, Inc.
235 West Maple Ave.
Monrovia, CA 91016
(213) 359-2593

Chamberlain Mfg. Co.
845 Larch Ave.
Elmhurst, IL 60126
(312) 279-3600

Champion Home Builders
5573 E. North St.
Dryden, MI 48428
(313) 796-2211

Chemical Processors, Inc.
P. O. Box 10636
St. Petersburg, FL 33733
(813) 822-3689

Clary Corp.
320 West Clary Ave.
San Gabriel, CA 91776
(213) 287-6111

Coating Laboratories
505 South Quaker
Tulsa, OK 74120

Cole Solar Systems, Inc.
440 A. East St. Elma Rd.
Austin, TX 78745
(512) 444-2565

Columbia Solar Energy Division
55 High St.
Holbrook, MA 02343
(617) 767-0513

Communications Satellite Corp.
950 L'enfant Plaza, S.W.
Washington, D.C. 20024

Conserdyne Corp.
4437 San Fernando Rd.
Glendale, CA 91204
(213) 246-8409

Contemporary Systems, Inc.
68 Charlonne St.
Jaffrey, NH 03452
(603) 532-7972

Corning Glass Works
Electrical Products Division HP C7
Corning, NY 14830

Crimsco, Inc.
5001 E. 59th St.
Kansas City, MO 64130
(816) 333-2100

Croton Chemical Co.
10 Harmich Rd.
South Plainfield, NJ 07080
(201) 754-2900

Crow-Sterner Associates
5911 Southern Hills Drive
Houston, TX 77069

SOLAR AND SOLAR RELATED FIRMS (continued)

Crystal Systems, Inc.
P. O. Box 1057
Salem, MA 01970
(617) 745-0088

Cushing Instruments
7911 Herschel Ave., Suite 214
La Jolla, CA 92037
(714) 459-3433

Dalton Tanks & Supply, Inc.
56166 Handley Rd.
Yucca Valley, CA 92284
(714) 364-2230

Daystar Corp.
90 Cambridge St.
Burlington, MA 01803
(617) 272-8460

L. M. Dearing Associates, Inc.
12324 Ventura Blvd.
Studio City, CA 91604
(213) 769-2521

Del Sol Control Corp.
11914 U.S. 1
Juno, FL 33408
(305) 626-6116

Delevan Electronics Inc.
14605 N. 73rd St.
Scottsdale, AZ 85260
(602) 948-6350

Delta-T
Dept. 3E-1
3731 Kenora Dr.
Spring Valley, CA 92077

Desert Sunshine Exposure Tests, Inc.
Box 185, Black Canyon Stage
Phoenix, AZ 85020
(602) 465-7525

Devices and Services Co.
3501-A Milton
Dallas, TX 75205
(214) 368-5749

Diy-Sol, Inc.
P. O. Box 614
Marlboro, MA 01752

Dow Chemical
Box 1605
Freeport, TX 77541
(713) 238-1051

Dow Corning
Mail No. C02314
Midland, MI 48640

Dynaire
8519 Eastern
San Antonio, TX 78216
(512) 349-6259

E&K Service Co.
16824 74th Ave. N.E.
Bothell, WA 98011
(206) 486-6660

E-Systems
Energy Technology Center
P. O. Box 6118
Dallas, TX 75222

Eaton Corporation
Controls Division
191 E. North Ave.
Carol Stream, IL 60187
(312) 682-8044

Ecotechnology
P. O. Box 181
Del Mar, CA 92014

SOLAR AND SOLAR RELATED FIRMS (continued)

Ecotope Group
747 16th East
Seattle, WA 98112
(206) 322-3753

Edwards Engr. Corp.
101 Alexander Ave.
Pompton Plains, NJ 07444
(201) 835-2808

Elcam, Inc.
5330 Debbie Ln.
Santa Barbara, CA 93111
(805) 967-6527

Energy Applications Inc.
P. O. Box 5694
Titusville, FL 32780
(305) 269-4893

Energy Converters Inc.
2501 N. Orchard Knob Ave.
Chattanooga, TN 37406
(615) 624-2608

Energy Dynamics Corp.
327 W. Vermillo St.
Colorado Springs, CO 80903
(303) 475-0332

Energy Engr. Inc.
P. O. Box 1156
Tuscaloosa, AL 35401

Energy Systems, Inc.
634 Crest Drive
El Cajon, CA 92021
(714) 447-1000

Enersol Company
First International Bldg., Suite 1800
Dallas, TX 75270
(214) 748-8511

Enertech Corp.
P. O. Box 420
Norwich, VT 05055

Eppley Laboratory Inc.
12 Sheffield Ave.
Newport, RI 02840
(401) 847-1020

Erie Mfg. Co.
4000 S. 13th St.
Milwaukee, WI 53221

Fafco Inc.
138 Jefferson Dr.
Menlo Park, CA 94025
(415) 321-3650

Falbel Energy Systems Corp.
472 Westover Rd.
Stamford, CT 06902
(203) 357-0626

Flagala Corp.
9700 W. Hwy. 98
Panama City, FL 32401
(904) 234-2141

Florida Solar Energy Center
300 State Rd. 401
Cape Canaveral, FL 32920
(305) 783-0300

Ford Products Corp.
Ford Products Rd.
Valley Cottage, NY
(914) 358-8282

Friedrich
4200 North Pan Am Expressway
P. O. Box 1540
San Antonio, TX 78245
(512) 225-2000

LISTING OF SOLAR AND SOLAR RELATED FIRMS

Future Systems, Inc.
12500 W. Cedar Rd.
Lakewood, CO 80228
(303) 989-0431

General Atomic Co.
P. O. Box 81608
San Diego, CA 92138

General Electric Co.
Space Div.
P. O. Box 8661 Bldg. 7
Philadelphia, PA 19101
(215) 962-2112

General Energy Devices, Inc.
2991 Weat Bay Dr.
Largo, FL 33540
(813) 586-3585

Gould Inc.
Gould Center
Rolling Meadows, IL 60008
(312) 640-4000

Grundfus Pump Co.
2555 Clovis Ave.
Clovis, CA 93612
(209) 299-9741

Halstead & Mitchell
Hwy. 72 West
P. O. Box 1110
Scottsboro, AL 35768
(205) 259-1212

Hamilton Research
1836 Lake St.
Glendale, CA 91201
(213) 241-3057

Hawthorne Industries, Inc.
1501 South Dixie Highway
West Palm Beach, FL 33401
(305) 659-5400

Helid Associates
P. O. Box 17960
Tucson, AZ 85731
(602) 792-2800

Helios Corporation
2120 Angus Rd.
Charlottsville, VA 22901
(804) 977-3719

Heliotherm, Inc.
W. Lenni Rd.
Lenni, PA 19052
(215) 459-9030

Heliothermics
10 Delores Street.
Greenville, SC 29605
(803) 277-6581

Heliotrope General
3733 Kenora Drive
Spring Valley, CA 92077
(714) 460-3930

Hexcel Corp.
11711 Dublin Blvd.
Dublin, CA 94566
(415) 828-4200

Hi-Tech Inc.
3024 16th Street
Zion, IL 60099
(312) 746-2447

SOLAR AND SOLAR RELATED FIRMS (continued)

Highland Plating Co.
1128 No. Highland Ave.
Hollywood, CA 90038
( ) 469-2289

Hollingsworth & Jackson
2121 Governors Circle
P. O. Box 10899
Houston, TX 77018
(713) 681-4811

Honeywell Inc.
2600 Ridgeway Pkwy.
Minneapolis, MN 55413
(612) 378-2750

Hubbell
45 Seymour St.
Stratford, CT 06497
(203) 378-2659

International Business Machines Corp.
Box 218
Yorktown Heights, NY 10598
(914) 945-1088

IMC Instruments Inc.
6659 North Sydney Place
Glendale, WI 53209

ITT Fluid Handling Division
4711 Gulf Rd.
Skokie, IL 60076
(312) 677-4030

Ilse Engr. Inc.
7177 Arrowhead Rd.
Duluth, MN 55811
(218) 729-6858

Independent Energy Inc.
P. O. Box 363
Kingston, RI 02881

Independent Living Inc.
5715 Buford Hwy., N.E.
Doraville, GA 30340
(404) 455-0927

Industrial Systems Inc.
1121 Fresno
San Antonio, TX 78201
(512) 736-2201

International Environment Corp.
83 S. Water St.
Greenwich, CT 06830
(203) 531-4490

International Rectifier
Semiconductor Div.
233 Kansas St.
El Segundo, CA 90245
(213) 322-3331

International Solarthermics Corp.
Box 397
Nederland, CO 80466
(303) 258-3272

Intertechnology Corp.
100 Main St.
Warrenton, VA 22166
(703) 347-7900

Jackson Mfg. Co.
P. O. Box 11168
Chattanooga, TN 37401
(615) 867-4700

Jacobs-Del Solar Systems
251 South Lake Ave.
Pasadena, CA 91101
(213) 449-2171

Johnson Controls
Penn Division
1302 E. Monroe St.
Goshen, IN 46526

SOLAR AND SOLAR RELATED FIRMS (continued)

Kalwall Corp.
P. O. Box 237
Manchester, NH 03105
(603) 599-1500

Kastek Corp.
P. O. Box 8881
Portland, OR 97208

Kennecott Copper Corp.
128 Spring St.
Lexington, MA 02173
(617) 862-8268

Largo Solar Systems Inc.
2525 Key Largo Lane
Ft. Lauderdale, FL 33312
(305) 583-8090

Lennox Industries Inc.
200 S. 12th Ave.
Marshalltown, IA 50158
(515) 754-4011

Libby-Owns-Ford
(LOF Solar Energy Systems)
1701 E. Broadway
Toledo, OH 43605
(419) 247-4350

LOF Brothers Solar Appliances
1615 Seventeenth St.
Denver, CO 80202
(303) 573-0696

MND Inc.
P. O. Box 15534
Atlanta, GA 30333
(404) 873-1812

Mann-Russell Electronics, Inc.
1401 Thorne Rd.
Tacoma, WA 98421
(206) 383-1591

March Mfg. Co.
P. O. Box 87
1819 Pickwick Ave.
Glenview, IL 60025

Mar-Scot Solar Pac Systems
10639 S.W. 185th Terrace
Miami, FL 33157
(305) 233-0711

Martin Processing, Inc.
P. O. Box 5068
Martinsville, VA 24112
(703) 629-1711

Matrix Inc.
537 South 31st St.
Mesa, AZ 85204
(602) 832-1380

McDonnell Douglas Astronautics Co.
5301 Bolsa Ave.
Huntington Beach, CA 92647
(714) 896-4323

Mid-West Technology Inc.
P. O. Box 2638
Dayton, OH 45426
(513) 274-6020

Mobil Tyco Solar Energy Corp.
16 Hickory Drive
Waltham, MA 02154

SOLAR AND SOLAR RELATED FIRMS (continued)

Mor-Flo Industries Inc.
18450 South Miles Rd.
Cleveland, OH 44128
(213) 663-7300

Motorola, Inc.
Solar Energy Dept.
P. O. Box 2953
Phoenix, AZ 85062
(602) 244-5511

NRG Ltd.
901 Second Ave. East
Coralville, IA 52241
(319) 354-2033

National Energy Corp.
21716 Kenrick Ave.
Lakeville, MN 55044

National Plastics, Inc.
Lab Sciences Division
P. O. Box 1236
Boca Raton, FL 33432
(305) 392-0501

National Solar Corp.
Novelty Lane
Essex, CT 06426
(203) 676-1644

Natural Energy Systems
1632 Pioneer Way
El Cajon, CA 92020
(714) 440-6411

Natural Power Inc.
Francestown Turnpike
New Boston, NH 03070

Navajo Air Equipment Inc.
610 S. 35 th St.
Phoenix, AZ

New Jersey Aluminum Co.
1007 Jersey Ave.
P. O. Box 73
North Brunswick, NJ 08902
(201) 249-6869

Northrup, Inc.
302 Nichols Dr.
Hutchins, TX 75141
(214) 225-4291

O.E.M. Products, Inc.
Solarmatic Division
2413 E. Garden St.
Tampa, FL 33605
(813) 247-5947

Olin Brass Inc.
Olin Corporation
East Alton, IL 62024
(618) 258-2770

Olympic Plating Industries, Inc.
208 15th Street, S.W.
Canton, OH 44707
(216) 452-8856

Optical Coating Lab, Inc.
P. O. Box 1599
Santa Rosa, CA 95403

Opto Technology, Inc.
(Sun Trac Corp.)
1674 South Wolf Rd.
Wheeling, IL 60090

Oriel Corp.
15 Market St.
Stamford, CT 06902
(203) 357-1600

SOLAR AND SOLAR RELATED FIRMS (continued)

Owens Enterprises, Inc.
436 North Fries Avenue
P. O. Box 967
Wilmington, CA 90744

Owens-Illinois Inc.
P. O. Box 1035
Toledo, OH 43666
(419) 242-6543

PPG Industries, Inc.
One Gateway Center
Pittsburgh, PA 15222
(412) 434-3552

Pacific Sun, Inc.
540 Santa Cruz Ave.
Menlo Park, CA 94025
(415) 328-4588

Payne, Inc.
1910 Forest Dr.
Annapolis, MD 21401
(301) 268-6150

People/Space Co.
259 Marloboro St.
Boston, MA 02116
(617) 261-2064

R-M Products
5010 Cook St.
Denver, CO 80216
(303) 825-0203

Ranco
601 West Fifth Ave.
Box 8187
Columbus, OH 43201

Ray Pak, Inc.
3111 Agoura Rd.
P. O. Box 5790
Thousand Oaks, CA 91360
(213) 889-1500

Refrigeration Research
525 N. 5th St.
Brighton, MI 48116
(313) 227-1151

Research Products Corp.
P. O. Box 1467
Madison, WI 53701
(608) 257-8801

Resource Technology Corp.
151 John Downey Dr.
New Britain, CT 06051
(203) 224-8155

Revere Copper and Brass, Inc.
Solar Energy Dept.
P. O. Box 151
Rome, NY 13440
(315) 338-2022

Reynolds Metals Co.
P. O. Box 27003
Richmond, VA 23261
(804) 281-3026

Rho Sigma
15150 Raymer
Van Nuys, CA 91405
(213) 342-4376

Roark, C.F., Welding & Engr. Co.
133 N. Green St.
Browsburg, IN 46112
(317) 852-3163

SOLAR AND SOLAR RELATED FIRMS (continued)

Robertshaw Controls Co.
P. O. Box 2000
4190 Temescal St.
Corona, CA 91720
(714) 734-2600

Rockwell International
6633 Canoga Ave.
Canoga Park, CA 91304
(213) 884-2434

SES, Inc.
One Trailee Industrial Park
New Wark, DE 19711
(302) 731-0990

S. W. Enter-Tech, Inc.
3030 S. Valley View Blvd.
Las Vegas, NV 89102
(702) 873-1975

Scientific-Atlanta
3845 Pleasantdale Rd.
Atlanta, GA 30340
(404) 449-2000

Scientifico
35985 Row River Rd.
Cottage Grove, OR 97424

SEMCO
1091 S. W. 1st Way
Deerfield Beach, FL 33441
(305) 427-0040

Sennergetics
18621 Parthenia St.
Northridge, CA 91324
(213) 885-0323

Sensor Technology, Inc.
21012 Lassen St.
Chatsworth, CA 91311
(213) 882-4100

Shaw Pump, Inc.
9660 East Rush St.
P. O. Box 3336
South El Monte, CA 91733
(213) 443-1784
(213) 283-5156

Sheldahl Co.
P. O. Box 170
Northfield, MN 55057
(507) 645-5631

Sigma Research, Inc.
2950 George Washington Way
Richland, WA 99352
(509) 946-0663

Siltec Corp.
3717 Haven Ave.
Menlo Park, CA 94025
(415) 365-8600

Simons Solar Environmental Systems, Inc.
24 Carlisle Pike
Mechanicsburg, PA 17055
(717) 697-2778

Skytherm Processes Engineering
2424 Wilshire Blvd.
Los Angeles, CA 90057

A. O. Smith Corp.
Box 28
Kankakee, IL 60901

SOLAR AND SOLAR RELATED FIRMS (continued)

Sol-Aire
465 McCormick St.
San Leandro, CA 94577
(415) 632-5400

Solar, Inc.
P. O. Box 246
Mead, NE 68041

Solar Age Systems
P. O. Box 1983
217 E. Hickory
Denton, TX 76201
(817) 387-4318

Solar-Aire
P. O. Box 276
N. Liberty, IA 52317
(319) 626-2343

Solar American
P. O. Box 7239
Hampton, VA 23666

Solar Applications, Inc.
7926 Convoy Court
San Diego, CA 92111
(714) 292-1857

Solar Comfort Systems, Div.
Suite 606
4853 Cordell Ave.
Bethesda, MD 20014
(301) 652-8941

Solar Control Corp.
5595 Arapahoe Rd.
Boulder, CO 80302
(303) 449-9180

Solar Controlar, Inc.
P. O. Box 8703
Orlando, FL 32806
(305) 851-8664

Solar Corp. of America
100 Main St.
Warrenton, VA 22186
(703) 347-7900

Solar Development, Inc.
4180 West Roads Dr.
West Palm Beach, FL 33407
(305) 842-8935

Solar Dynamics, Inc.
2427 E. 11th Ave.
Hialeah, FL 33013
(305) 688-4393

Solar Electric International, Inc.
Sarasota Bank Bldg.
Sarasota, FL 33577

Solar Energy Products, Inc.
1208 N. W. 8th Ave.
Gainesville, FL 32601
(904) 377-6527

Solar Energy Resources Corp.
10639 S. W. 185 Terrace
Miami, FL 33157
(305) 233-0711

Solar Energy Systems
1243 S. Florida Ave.
Rockledge, FL 32955
(305) 632-6251

SOLAR AND SOLAR RELATED FIRMS (continued)

Solar Thermics Enterprises, Ltd.
110 N. Walnut
Creston, IA 50801
(515) 782-8566

Solar Utilities Co.
406 North Cedros
Solana Beach, CA 92075
(714) 452-8822

Solarator
P. O. Box 277
Madison Hts., MI 48071
(313) 642-9377

Solaray, Inc.
324 S. Kidd St.
Whitewater, WI 53190
(414) 473-2525

Solarcoa
2115 E. Spring St.
Long Beach, CA 90806
(213) 426-7655

Solarex Corp.
1335 Piccard Drive
Rockville, MD 20850
(301) 948-0202

Solargenics, Inc.
9713 Lurline Ave.
Chatsworth, CA 91311
(213) 998-0806

Solargizer Corp.
220 Mulberry St.
Stillwater, MN 55082
(612) 739-0117

Solaron Mktg. Services Gp.
4850 Olive St.
Commerce City, CO 80022
(303) 759-0101

Solarponics
P. O. Box 1571
San Luis Obispo. CA 93406
(805) 543-3436

Solcan, Ltd.
126 Wychwood Pk.
London, Ontario, Canada N6G - 1R7
(519) 471-4069

Solec International, Inc.
2 Century Plaza, Suite 484
2049 Century Park East
Los Angeles, CA 90067

Solergy, Inc.
150 Green St.
San Francisco, CA 9411
(415) 398-6813

Sollos, Inc.
2231 S. Carmelina Ave.
Los Angeles, CA 90064
(213) 820-5181

Soltherm Corp.
7 West 14th St.
New York, NY 10011
(212) 691-4632

Soltrax, Inc.
720 Rankin Road N.E.
Albuquerque, MN 87107

Solus, Inc.
P. O. Box 35227
Houston, TX 77035
(713) 772-6416

Southeastern Solar Systems
4705 J. Bakers Ferry Rd.
P. O. Box 44066
Atlanta, GA 30336
(404). 691-1864

SOLAR AND SOLAR RELATED FIRMS (continued)

Southern Lighting Mfg. Co.
501 Elwell St.
Orlando, FL 32803
(305) 894-8851

Spectran/Instruments
P. O. Box 891
La Habra, CA 90631
(213) 694-3995

Spectrolab, Inc.
12484 Gladstone Ave.
Sylmar, CA 91342
(213) 365-4611

State Industries
Cumberland St.
Ashland City, TN 37015
(615) 792-4371

Stolle Corp.
1501 Michigan St.
Sidney, OH 45365
(513) 492-1111

Sun Power Systems, Ltd.
1024 West Maude Ave.
Suite 203
Sunnyvale, CA 94086
(408) 738-2442

Sun Stone
P. O. Box 941
Sheboygan, WI 53081
(414) 452-8194

Sun Systems, Inc.
P. O. Box 155
Eureka, IL 61530
(309) 467-3632

Sundu Co.
3319 Keys Lane
Anaheim, CA 92804
(714) 828-2873

Sunearth, Inc.
Sales Div.
Box Sc.
Granlin/Marietta Bldg.
Progress Drive
Montgomeryville, PA 18936
(215) 699-7892

Sunergy Power, Ltd.
400 W. Main St.
Babylon, NY 11702
(516) 587-0611

Sunglaze, Inc.
P. O. Box 2634
Olympic Valley, CA 95730

Sunpower Systems Corp.
2123 S. Priest Rd.
Suite 216
Tempe, AZ 85282
(602) 968-6387

Sunstream (Grumman Corp.)
4175 Veteran's Memorial Highway
Ronkonkoma, NY 11779

Suntap, Inc.
Box 754
Arlington Heights, IL 60006
(312) 255-5654

Sunworks, Div. of Enthrone, Inc.
Box 1004
New Haven, CT 06508
(203) 453-6191

SOLAR AND SOLAR RELATED FIRMS (continued)

Sunworks, Inc.
669 Boston Post Rd.
Guilford, CT 06437
(203) 934-6301

Swedcast Corp.
7350 Empire Drive
Florence, KY 41042

Technology Applications Laboratory
1670 Highway A1A
Satellite Beach, FL 32837
(305) 777-1400

Texas Electronics, Inc.
P. O. Box 7225
Dallas, TX 75209
(214) 631-2490

Texas Solar, Inc.
6119 Jessamine
Suite 1
Houston, TX 77081
(713) 777-1368

Thermon Manufacturing
P. O. Box 609
100 Thermon Drive
San Marcos, TX 78666
(512) 392-5801 Ext. 239

Thomason Solar Homes, Inc.
6802 Walkermill Road, S.E.
Washington, D. C. 20027
(301) 336-0009

3 M Company
3 M Center
St. Paul, MN 55101
(612) 733-1110

Tranter
735 E. Hazel St.
Lansing, MI 48909
(517) 372-8410

Turbonics, Inc.
11200 Madison Ave.
Cleveland, OH 44102
(216) 228-9663

Tuthill Pump Company
12500 South Crawford Ave.
Chicago, IL 60658
(312) 389-2500

U. S. Solar Pillow
P. O. Box 987
416 E. Oak
Tucumcari, NM 88401
(505) 461-2608

Unit Electric Control, Inc.
130 Atlantic Dr.
Maitland, FL 32751
(305) 831-1900

United Technologies
400 Main St.
East Hartford, CT 06108

Varian Associates
611 Hansen Way
Palo Alto, CA 94303

Vermont Solar Group, Inc.
P. O, Box 292
Warren, VT 05674
(802) 496-2983

Vinyl-Fab Industries
930 East Drayton
Ferndale, MI 48220
(313) 399-8745

Westinghouse Electric Corp.
Skyline Center
Suite 1307
5205 Leesburg Pike
Falls Church, VA 22041
(202) 833-5950

Wilcon Corp.
3310 S. W. Seventh
Ocala, FL 32670
(904) 732-2550

Willey Corporation
Box 670
Melbourne, FL 32901
(305) 727-2046

Wiltronics
3110 S. W. 7th St.
Ocala, FL
(904) 732-2550

Wormser Scientific Corp.
88 Foxwood Rd.
Stamford, CT 06903
(203) 329-2001

Ying Mfg. Corp.
1940 W. 144 St.
Gardena, CA 90249
(213) 770-1756

York Division
Borg-Warner Corp.
P. O. Box 1592
York, PA 17405
(717) 846-7890

Zome Works Corp.
Box 712
Albuquerque, NM 87108

APPENDIX D

REFERENCES

This appendix contains a list of references which have been utilized during the project. Included are articles, books, and government documents.

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APPENDIX E

SOLAR SYSTEM DESIGN AND INSTALLATION TIME

This appendix contains information used with the University of New Mexico Study and the MITRE study regarding collector area and installation time. Tables are included for Solar Domestic Hot Water and Solar Space Heating/Domestic Hot Water. Data are listed by State (UNM Study) and by Region (MITRE Study).

APPROXIMATE COLLECTOR AREA REQUIRED FOR 75% SOLAR DOMESTIC HOT WATER
(USED WITH NEW MEXICO STUDY)

ASSUMPTIONS:

- 80 Gallons/Day Required
- Liquid and Air Collectors Produce the Same Energy

STATE	AREA NEEDED (Ft^2)	DESIGN & INSTALLATION TIME (HOURS)
Alabama	75	52
Arizona	50	50
Arkansas	75	52
California	65	51
Colorado	65	51
Connectitutt	95	54
Delaware	95	54
Florida	65	51
Georgia	75	52
Idaho	75	52
Illinois	95	54
Indiana	95	54
Iowa	95	54
Kansas	75	52
Kentucky	95	54
Louisiana	75	52
Maine	125	56
Maryland	95	54
Massachusetts	125	56
Michigan	125	56
Minnesota	95	54
Mississippi	75	52
Missouri	75	52
Montana	75	52
Nebraska	75	52
Nevada	65	51
New Hampshire	125	56

State	Area	Time
New Jersey	95	54
New Mexico	50	50
New York	125	56
North Carolina	75	52
North Dakota	75	52
Ohio	110	55
Oklahoma	65	54
Oregon	95	55
Pennsylvania	110	54
Rhode Island	95	55
South Carolina	75	52
South Dakota	75	52
Tennessee	75	52
Texas	70	52
Utah	65	51
Vermont	125	56
Virginia	95	54
Washington	125	56
West Virginia	95	54
Wisconsin	95	54
Wyoming	75	52

APPROXIMATE COLLECTOR AREA REQUIRED FOR 75% SOLAR SPACE HEATING AND HOT WATER
(USED WITH NEW MEXICO STUDY)

ASSUMPTIONS:

- 80 Gallons/Day of Hot Water
- Space Heating Based on Balcomb-Hedstrom Solar Heating Maps
- 1500 Ft^2 House with 10 $BTU/DD/Ft^2$.

STATE	AREA NEEDED (Ft^2)	DESIGN & INSTALLATION TIME (HOURS)
Alabama	400	164
Arizona	390	163
Arkansas	625	183
California	270	154
Colorado	670	187
Connecticutt	1030	217
Delaware	780	196
Florida	170	145
Georgia	400	164
Idaho	885	205
Illinois	1100	223
Indiana	1030	217
Iowa	1100	223
Kansas	705	190
Kentucky	890	205
Louisiana	400	164
Maine	1240	234
Maryland	780	196
Massachusetts	1040	218
Michigan	1190	230
Minnesota	1180	229
Mississippi	400	164
Missouri	775	196
Montana	965	211
Nebraska	815	199

STATE	AREA	TIME
Nevada	620	183
New Hampshire	1240	234
New Jersey	890	205
New Mexico	445	168
New York	1290	238
North Carolina	625	183
North Dakota	1095	222
Ohio	1100	223
Oklahoma	570	178
Oregon	890	205
Pennsylvania	1105	223
Rhode Island	970	217
South Carolina	455	169
South Dakota	965	211
Tennessee	705	190
Texas	400	164
Utah	700	189
Vermont	1290	238
Virginia	745	193
Washington	1040	218
West Virginia	970	212
Wisconsin	1180	229
Wyoming	775	196

DOMESTIC HOT WATER ONLY
(USED WITH MITRE STUDY)

REGION	SIZE	TIME
Boston	64	52
Washington	64	52
Albany	64	52
Los Angeles	56	54
Charleston	64	52
Bismark	48	50
Nashville	64	52
Fort Worth	64	52
Omaha	64	52
Seattle	48	50
Phoenix	48	50
Miami	56	54
Madison	64	52
Chicago	48	50
Cape Hatteras	64	52
Atlanta	80	53

HOT WATER AND SPACE HEATING COMBINED
(USED WITH MITRE STUDY)

REGION	SIZE	TIME
Boston	360	171
Washington	288	165
Albany	450	179
Los Angeles	320	168
Charleston	112	151
Bismark	450	179
Nashville	240	161
Fort Worth	128	162
Omaha	450	179
Seattle	250	162
Phoenix	96	149
Miami	96	149
Madison	450	179
Chicago	550	187
Cape Hatteras	160	163
Atlanta	176	164

APPENDIX F

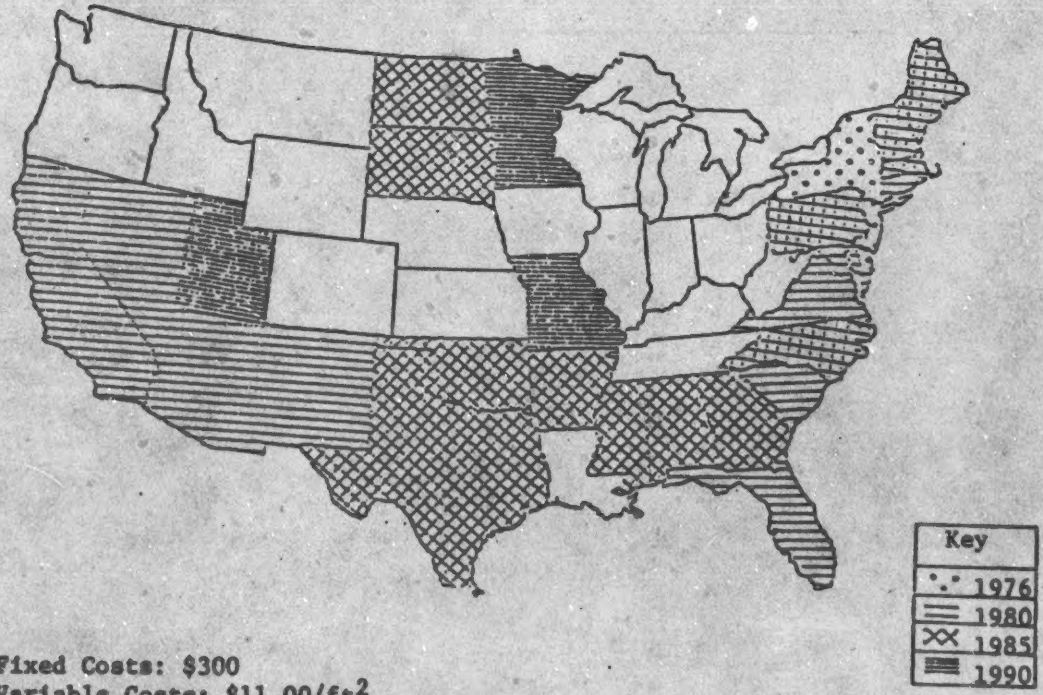
SOLAR FEASIBILITY MAPS, UNIVERSITY OF NEW MEXICO STUDY

This appendix contains maps of the United States indicating in which year solar energy is expected to become economically feasible. Maps are included for domestic hot water systems and for space heating systems.

SOLAR FEASIBILITY

DOMESTIC HOT WATER*

(Real Interest Rate - 2.5%)


Key
1976
1980
1985
1990

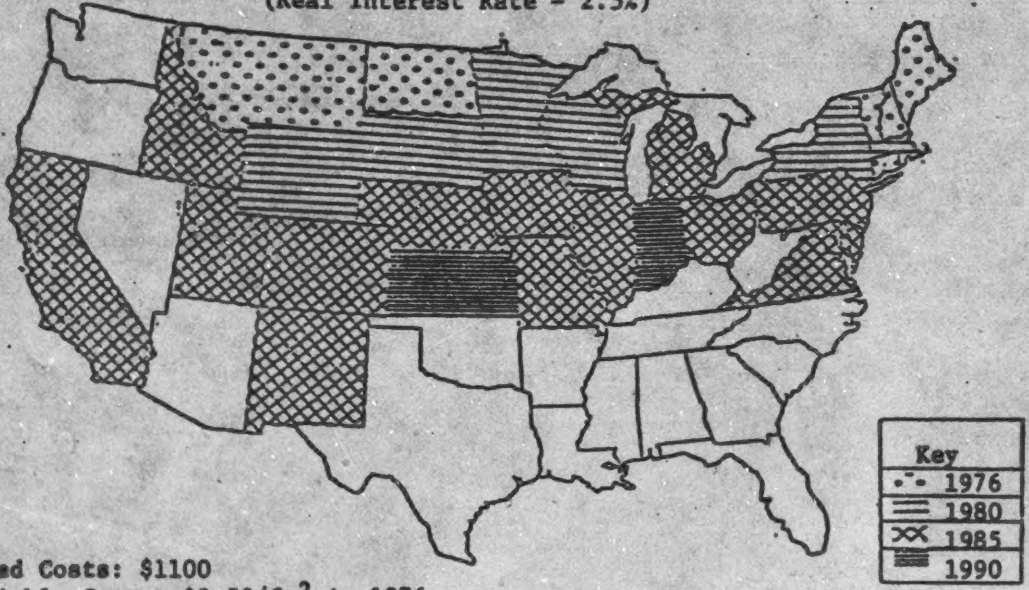
*Fixed Costs: $300
Variable Costs: $11.00/ft^2
Operation & Maintenance: 1.0%/yr
System Life: 20 years

SOLAR FEASIBILITY

RESIDENTIAL SPACE HEATING

Standard Air System*

(Real Interest Rate - 2.5%)



*Fixed Costs: $1100
Variable Costs: $9.50/ft^2 in 1976
decreasing to $8.00/ft^2 in 1990
Operation & Maintenance: 0.75%/yr
System Life: 30 years

APPENDIX G

EXISTING AND PROJECTED HOUSING STOCK

This appendix contains statistics on single-family housing units. The data were compiled from the 1972 OBERS Projections and The 1970 Census of Housing, and are arranged by State.

Housing Statistics Summary *

	Percent of U.S. Projected Population Growth**	1970 Single-Family Housing Stock***	Single-Family Units as a Percent of the Total †	Adjustment Ratio ††	Single-Family Units as a Percent of the U.S. Total†††
Alabama	1.51	929	83.3	1.16	1.92
Arizona	2.15	426	73.6	1.02	1.03
Arkansas	.82	577	85.4	1.19	1.18
California	11.82	4696	67.3	.93	10.15
Colorado	1.57	534	72.0	1.00	1.18
Connecticut	1.59	572	59.1	.82	1.25
Delaware	.37	133	75.9	1.05	.29
Florida	9.80	1740	69.9	.97	4.31
Georgia	3.09	1107	75.3	1.05	2.42
Idaho	.05	192	80.8	1.12	.37
Illinois	4.55	2197	59.5	.83	4.65
Indiana	2.74	341	78.3	1.09	2.83
Iowa	.38	783	82.0	1.14	1.88
Kansas	.08	645	81.9	1.14	1.24
Kentucky	1.80	850	80.2	1.11	1.80
Louisiana	.69	897	78.3	1.09	1.78
Maine	- .01	230	68.3	.95	.44
Maryland	3.17	852	69.0	.96	1.94
Massachusetts	2.79	925	50.4	.70	2.05
Michigan	4.13	2162	76.1	1.06	4.54
Minnesota	1.73	895	73.5	1.02	1.88
Mississippi	.55	598	85.8	1.19	1.20
Missouri	1.77	1228	73.8	1.02	2.52
Montana	- .08	180	74.8	1.04	.35
Nebraska	.16	408	79.7	1.11	.79
Nevada	.63	105	61.0	.85	.26
New Hampshire	.42	158	63.8	.89	.36
New Jersey	4.10	1334	57.9	.80	2.96
New Mexico	.27	263	81.8	1.13	.53
New York	6.37	2487	40.4	.56	5.39
North Carolina	3.25	1341	82.9	1.15	2.89
North Dakota	- .13	149	74.5	1.03	.27
Ohio	4.56	2482	72.0	1.00	5.19
Oklahoma	1.0	798	85.1	1.18	1.62
Oregon	1.03	570	77.5	1.08	1.19
Pennsylvania	2.72	2821	72.8	1.01	5.75
Rhode Island	.29	159	51.7	.72	.34
South Carolina	.88	669	83.1	1.15	1.40
South Dakota	- .04	178	80.4	1.12	.34
Tennessee	2.98	1041	80.3	1.11	2.29
Texas	5.51	3069	80.6	1.12	6.41
Utah	.57	234	75.2	1.04	.51
Vermont	.17	99	66.4	.92	.21
Virginia	3.51	1112	74.9	1.04	2.48
Washington	.93	913	75.8	1.05	1.83
West Virginia	.23	491	82.9	1.15	.96
Wisconsin	1.37	999	70.7	.98	2.04
Wyoming	.00	86	75.0	1.04	.16

*Statistics contained in this Table were computed by the authors from data acquired from the 1972 OBERS Projections (Series E) and the 1970 Census of Housing.

**Based upon an increase of 42, 181, 136 for the ration as a whole from 1970 to 1990. May not add to 100.0 (one-hundred percent) due to round-off errors plus the exclusion of Alaska, Hawaii, and the District of Columbia.

***Expressed in thousands

†Excludes mobile homes for each state. Derived by dividing the number of single-family units by total housing inventory. The national average was 69.4 percent.

††Represents the ratio of each state's single family units percent of the total housing stock (for that state) to the national average of 71.8 percent (Alaska, Hawaii, and District of Columbia excluded). See the text for a fuller explanation. Due to round off errors some of the computed percents may not reflect the actual percents.

††† Represents each state's percentage of the national single-family housing inventory in 1970. Mobile homes are excluded from the data. Percents will not add to 100.0 due to round off errors and the exclusion of Alaska, Hawaii, and the District of Columbia.

ESTIMATES OF 1976 GROSS AND NET SINGLE FAMILY DETACHED HOUSING STARTS

States	LOW (.9 Million)			MIDPOINT (1.3 Million)			HIGH (1.7 Million)		
	Gross Housing Starts	Net Housing Starts	Percent of the Total (1976)	Gross Housing Starts	Net Housing Starts	Percent of the Total (1976)	Gross Housing Starts	Net Housing Starts	Percent of the Total (1976)
Alabama	16.020	11.707	1.57	23.313	14.430	2.27	30.906	14.742	3.01
Arizona	17.125	14.704	3.09	23.691	18.124	4.23	28.443	18.516	5.07
Arkansas	9.148	6.506	1.46	13.413	8.020	2.13	18.024	8.193	2.86
California	96.692	73.786	1.79	138.954	90.948	2.56	179.980	92.916	3.32
Colorado	13.206	10.523	2.10	18.729	12.970	2.97	23.648	13.251	3.74
Connecticut	11.536	8.715	1.73	16.624	10.742	2.49	21.652	10.975	3.24
Delaware	3.290	2.626	2.12	4.664	3.237	2.99	5.883	3.307	3.76
Florida	73.654	63.502	3.17	101.748	78.272	4.34	121.784	79.966	5.18
Georgia	27.186	21.663	2.10	38.554	26.702	2.97	48.680	27.279	3.74
Idaho	1.170	0.364	.60	1.979	0.449	1.01	3.289	0.458	1.69
Illinois	35.479	25.103	1.44	52.094	20.941	2.10	70.178	31.611	2.84
Indiana	26.285	19.899	1.74	37.864	24.327	2.50	49.262	25.057	3.25
Iowa	33.783	29.325	3.32	46.557	36.146	4.54	55.442	36.928	5.39
Kansas	3.272	0.591	.50	5.773	0.728	.89	10.091	0.744	1.55
Kentucky	17.439	13.367	1.82	25.027	16.476	2.60	32.335	16.833	3.35
Louisiana	8.947	5.034	.95	13.864	6.205	1.47	20.417	6.339	2.17
Maine	0.897	-0.048	.39	1.700	-0.059	.74	3.207	-0.061	1.40
Maryland	24.756	20.285	2.38	34.794	25.003	3.32	43.157	25.544	4.12
Mass.	17.626	13.034	1.62	25.564	16.065	2.35	33.683	16.413	3.09
Michigan	39.369	29.174	1.63	57.065	35.959	2.36	75.106	36.737	3.10
Minnesota	16.045	11.823	1.61	23.295	14.572	2.32	30.750	14.888	3.06
Mississippi	7.062	4.419	1.12	10.694	5.447	1.69	15.181	5.565	2.40
Missouri	17.698	12.093	1.33	26.226	14.906	1.96	35.906	15.229	2.68
Montana	1.299	0.534	.70	2.124	0.658	1.15	3.379	0.672	1.83
Nebraska	2.908	1.177	.70	4.764	1.451	1.14	7.600	1.482	1.82
Nevada	4.207	3.588	2.96	5.833	4.422	4.07	7.037	4.518	4.90
New Hamp.	4.294	3.469	2.23	6.063	4.276	3.13	7.590	4.369	3.91
New Jersey	28.677	21.995	1.82	41.148	27.111	2.60	53.144	27.698	3.36
New Mexico	3.204	2.036	1.13	4.835	2.509	1.72	6.825	2.563	2.44
New York	35.799	23.848	1.26	53.395	29.395	1.87	73.917	30.031	2.59
N. Carolina	31.399	25.031	2.05	44.894	30.853	2.90	56.891	31.521	3.67
N. Dakota	-0.320*	-0.894	.23	-0.096	-1.102	.07	0.767	-1.126	.54
Ohio	42.001	30.389	1.52	61.297	37.446	2.22	81.686	38.257	2.95
Oklahoma	11.492	7.882	1.34	17.013	9.716	1.98	23.253	9.926	2.70
Oregon	10.085	7.413	1.60	14.651	9.137	2.31	19.365	9.335	3.05
Penn.	37.328	24.586	1.23	55.833	30.305	1.83	77.663	30.961	2.55
Rhode Is.	2.631	1.864	1.45	3.860	2.300	2.12	5.194	2.350	2.85
S. Carolina	12.762	9.606	1.71	18.414	11.840	2.46	24.032	12.097	3.21
S. Dakota	0.392	-0.327	.22	0.915	-0.403	.52	2.044	-0.412	1.17
Tennessee	27.649	22.214	2.25	38.734	27.381	3.15	48.432	27.973	3.94
Texas	55.395	41.202	1.63	80.581	50.786	2.36	106.049	51.884	3.10
Utah	5.787	4.617	2.11	8.204	5.691	2.98	10.350	5.815	3.76
Vermont	1.505	1.047	1.38	2.221	1.290	2.03	3.017	1.318	2.76
Virginia	30.070	24.398	2.27	42.398	30.073	3.19	52.926	30.724	3.97
Washington	10.576	6.326	1.09	16.066	8.044	1.65	22.927	8.218	2.36
W. Virginia	3.903	1.805	.77	6.268	2.225	1.24	9.727	2.274	1.92
Wisconsin	13.546	9.012	1.25	20.212	11.108	1.86	27.997	11.348	2.58
Wyoming	0.354	0.0	.41	0.661	0.0	.77	1.227	0.0	1.43

APPENDIX H

CONTRACTORS' SURVEY, STATISTICAL ANALYSIS

This appendix contains the methodology and results of the statistical analysis of data obtained by surveying contractors. Flow chart is given for the computer program used in carrying out the analysis.

APPENDIX H

STATISTICAL ANALYSIS OF CONTRACTOR SURVEY RESPONSES FOR MANHOUR REQUIREMENTS PER SOLAR SYSTEM

A statistical analysis was conducted to show the time requirement for each stage in a solar system (design, installation, maintenance and repair). Names and addresses of persons identified as potential solar contractor/builders and solar installers were obtained from:

1. National Solar Heating and Cooling Information Center.
2. Solar Energy Industries Association.
3. The Bureau of Housing and Urban Development, and ERDA demonstration projects.
4. Solar seminars and solar conferences.
5. Solar energy societies of several states.

Data were collected nationwide using the contractor survey form (Appendix J). The first part of the form asked questions regarding system type and the application area with which the respondent would be familiar. The second half contained questions on system size and time requirements. The statistical analysis was performed on the data extracted from the second half to derive the functional relationship between the time requirement and system size.

Survey Statistics

Six hundred and sixty-five forms were mailed. Twenty-five forms were returned unopened because of incorrect address, no forwarding address, or addressee unknown. Thirty-one percent of the list responded to the survey. 22.4% of the respondents supplied no information for the following reasons:

1. "Not qualified to fill out such forms."
2. "Not in business."
3. "Haven't installed any system yet."
4. "Only do design work for solar energy system."
5. "Don't fill out such forms."
6. "Studying socio-economic aspects of solar energy."

15.6% of the respondents supplied inconclusive information. Therefore, the conclusions are based on sixty-two percent of the response. Fifty percent of the responses were based on new installations. More than seventy-five percent of the responses were based on application in residential sectors, which supports assumptions made by the equipment group. 22.5% of the responses were based on commercial market. Seventy-three percent of responses were based on liquid systems, and 27% of responses were based on air systems. Ninety percent of responses were on flat-plate collector systems. The concentrating tracking and stationary collectors were used in less than 10% of the responses.

One question asked on the contractor survey form was, "How many persons are doing solar related work in your firm?" Response to this question determined that most firms employed 2 to 5 persons for solar related work.

The contractor survey form also asked, "Would you hire a solar designer and/or installer, if such a persons were available?" Response to this question was as follows:

1. 54.5% of respondents were willing to hire, if business growth warranted.
2. 35% of respondents had no particular need because of insufficient business.
3. 5.7% of respondents said no, because they wanted to train people themselves.
4. 4.8% of respondents did not answer the question.

Statistical Analysis

To determine the manhour requirement per installation, the data were divided into groups as shown in Figure H.1. These groups were based on the assumption that the manhour requirement for an installation may vary with

(1) building type (new or retrofit),

(2) sector (residential, commercial, etc.),

(3) application (domestic hot water (DHW), and space heating (SH).

Therefore it was decided to perform statistical analysis of these groups separately.

Manhour requirements for each installation were divided into four parts: manhours required for Design (t_D), Installation (t_I), Maintenance (t_M), and Repair (t_R). These four variables are assumed to be dependent on the size of collectors (s); therefore, there are four distinct sets of figures in each group for statistical analysis. Step by step procedure for analysis of these sets is shown in Figure H.2.

As a first step, the correlation co-efficient r_{st} was obtained for each set using the program CORRE. The value for t-statistics derived from r_{st} easily determined at what significance level the total collector are (s) and the time (t) are related. When the significance level

Figure E.1

FORMATION OF DATA GROUPS IN CONTRACTOR'S SURVEY BY BUILDING TYPE, BY SECTOR, BY APPLICATION

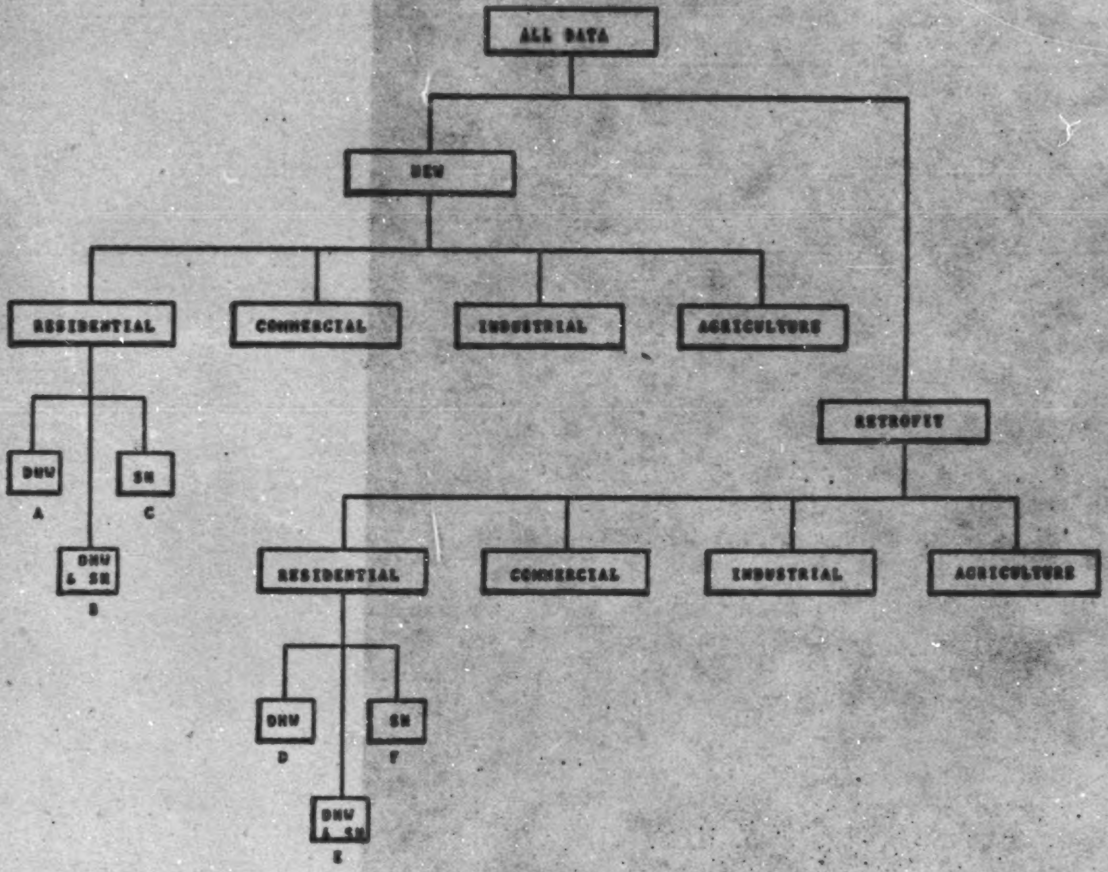
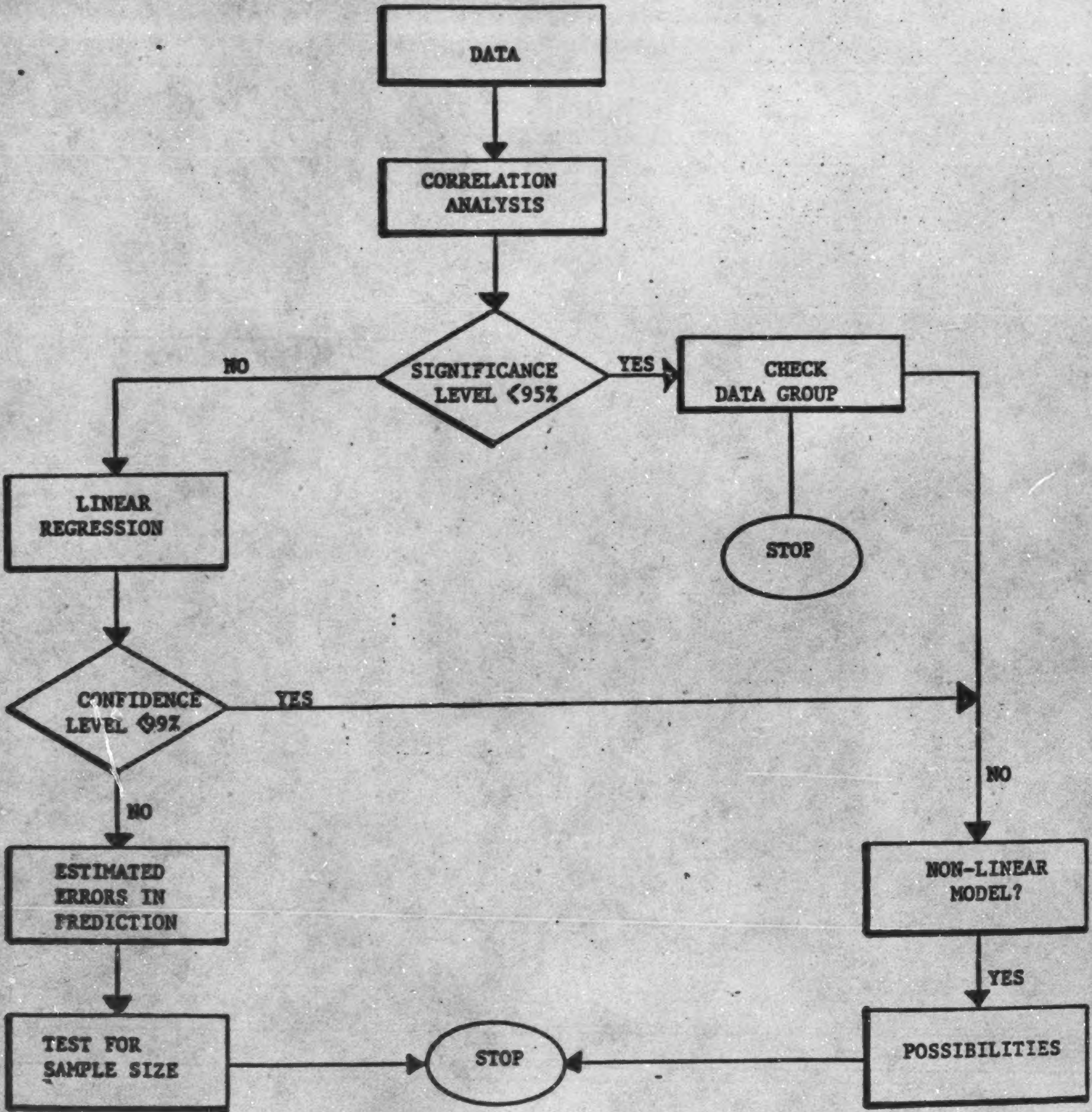

ALL DATA
NEW
RESIDENTIAL
COMMERCIAL
INDUSTRIAL
AGRICULTURE
DHW
A
SH
C
DHW & SH
B
RETROFIT
RESIDENTIAL
COMMERCIAL
INDUSTRIAL
AGRICULTURE
DHW
D
SH
F
DHW & SH
E

Figure H.2

STEPS INVOLVED IN STATISTICAL ANALYSIS


DATA
CORRELATION ANALYSIS
SIGNIFICANCE LEVEL <95%
NO
YES
CHECK DATA GROUP
STOP
LINEAR REGRESSION
CONFIDENCE LEVEL <99%
YES
NO
ESTIMATED ERRORS IN PREDICTION
TEST FOR SAMPLE SIZE
STOP
NO
NON-LINEAR MODEL?
YES
POSSIBILITIES

was 95% or above, a straight line fit of the data was obtained through the linear regression program MULTR. An analysis of variance table was also obtained and the F-statistics value was calculated. "Lack of Fit" test gave the confidence level for the straight line fit obtained. If the confidence level was 95% or better, the errors in predictions were estimated, and the Z-test for the adequacy of the sample size was performed. If the sample size is adequate for predictions with a 95% confidence level, then there exists a relationship between the time and the total collector area. This relationship may be used to predict time-values for systems with given values of total collector area. (t is a function of s.)

If the significance level for correlation is less than 95%, (or tht total number of observations less than 5), the data points are plotted on a graph to check the possibility of a non-linear model.

If linear regression passed the "Lack of Fit" test with less than a 95% confidence level, then several non-linear models were tested and checked. These results are discussed next.

Results

Very little information is available on new as well as retrofit residential space heating systems (groups C and F in Figure H.1). Therefore, the results of analysis on other groups are presented here. For convenience, the results on design data from all four groups are presented first, and then results on installation, maintenance and repair follow.

The results of the statistical analysis supported the assumptions made by the equipment group:

1. The solar demand in the residential sector will grow faster than demand in any other sector.
2. Systems using flat-plate liquid collectors will dominate the residential market.

The study of design procedures indicates that design time is fairly constant for a type of system, independent of the size. The same result was obtained through statistical analysis. The hypothesis that the design time is independent of total collector area could not be rejected for new space heating/domestic hot water (SH/DHW) design data, retrofit DHW design data and retrofit SH/DHW design data. The hypothesis was rejected for new DHW design data; the percent variability of the data explained was low and Z-test indicated that the sample size used in analysis is not adequate for accurate predictions. Thus, there was insufficient evidence to accept the hypothesis. For small variations in the total collector area, the design time for new DHW systems was almost the same, when 95% confidence level bands were considered in the calculations. Thus the design time is considered to be constant for all groups. The data on design time is depicted in Table H.2, and the results of regression analysis are shown in Tables H.3, H.4, H.5 and H.6. In Figures H.3, H.4, H.5, H.6, and H.7, where 95% confidence level bands are also drawn, the design time for the typical domestic hot water system is 15.3 manhours (new) and 18.62 manhours (retrofit). The total collector area for the typical DHW system is 50 square feet. The design time for the typical space heating and hot water combined system with 300 square feet total collector area is 53 manhours (new) and 24 manhours (retrofit).

That the installation time is a function of the total collector area is accepted for this project because the hypothesis of independence of installation time and collector area was rejected with sufficient evidence for all installation data. Table H.7 summarizes the response data on installation time versus collector area for each type of construction and each type of system. The tables H.8, H.9, H.10, and H.11 show the results of regression analysis on these data. The plots of the best fit equation

TABLE H.2

RESPONSE DATA ON DESIGN TIME VERSUS TOTAL COLLECTOR AREA

NEW				RETROFIT			
DHW		SH/DHW		DHW		SH/DHW	
COLLECTOR AREA (x)	DESIGN TIME (y)	COLLECTOR AREA (x)	DESIGN TIME (y)	COLLECTOR AREA (x)	DESIGN TIME (y)	COLLECTOR AREA (x)	DESIGN TIME (y)
23	2	490	20	1000	40	66	5
48	2	1053	60	40	12	96	10
80	40	4500	200	50	12	128	3
58	2	720	100	40	30	64	8
252	60	148	10	43	7	96	8
28	20	176	65	68	8	420	8
15	15	360	40	264	45		
36	10	724	50	44	8		
		1200	100	65	5		
		864	128				
		64	8				
		128	8				
		638	40				
		240	32				
		400	30				
		276	35				
		384	14				
		225	60				
		468	10				
		294	20				
		180	15				
		378	75				
		360	100				
		432	35				
		320	100				
		840	24				

TABLE H.3

RESULTS OF REGRESSION ANALYSIS ON NEW DHW DESIGN DATE

EQUATION	A	B	RES ERROR	R-SQUARE	MAX DEVIATION
Y = A * X	0.25415		154.75700	0.69920	19.66831
Y = A + B * X	3.63082	0.22924	145.19933	0.71777	18.03032
Y = A * EXP (B * X)	4.73824	0.01019	205.35751	0.60084	29.28911
Y = 1/(A + B * X)	0.29955	-0.00105	347.78824	0.32400	35.13691
Y = A + B/X	34.36414	-536.56295	383.89908	0.25381	27.76508
Y = A + B * LOG(X)	-51.62577	18.51997	214.56055	0.58296	18.82477
$Y = A * X^B$	0.54425	0.74657	298.28567	0.42022	26.22481
Y = X/(A + B * X)	0.28809	0.21148	785.05425	-0.52592	55.29674

EQUATION Y = A + B * X HAS MAXIMUM R-SQUARE

EQUATION Y = A + B * X HAS MINIMUM (MAXIMUM ABSOLUTE RESIDUAL)

TABLE H.4.

RESULTS OF REGRESSION ANALYSIS ON NEW SH/DHW DESIGN DATA

EQUATION	A	B	RES ERROR	R-SQUARE	MAX DEVIATION
Y = A * X	0.05640		1505.31186	0.29652	81.95226
Y = A + B * X	28.29849	0.04011	942.59361	0.55949	58.87638
Y = A * EXP (B * X)	26.21621	0.00056	1799.04162	0.15925	120.10142
Y = 1/(A + B * X)	0.04903	-0.00002	4344.17200	-1.03018	253.99434
Y = A + B/X	75.16252	-6572.02025	1702.21848	0.20450	126.29794
Y = A + B * LOG(X)	-166.52911	36.55584	1139.20195	0.46761	59.02750
$Y = A * X^B$	0.56945	0.69495	985.46792	0.53946	68.63725
Y = X/(A + B * X)	8.16295	0.01202	1899.99189	0.11207	127.70401

EQUATION Y = A + B * X HAS MAXIMUM R-SQUARE

EQUATION Y = A + B * X HAS MINIMUM (MAXIMUM ABSOLUTE RESIDUAL)

TABLE H.5.

RESULTS OF REGRESSION ANALYSIS ON RETROFIT DHW DESIGN DATA

EQUATION	A	B	RES ERROR	R-SQUARE	MAX DEVIATION
Y = A * X	0.05118		309.33828	-0.13002	31.48930
Y = A + B * X	12.77679	0.03222	155.28586	0.43274	23.71618
Y = A * EXP(B * X)	10.38440	0.00156	198.63873	0.27437	29.32327
Y = 1/(A + B * X)	0.11082	-0.00010	397.62213	-0.45252	34.74224
Y = A + B/X	38.24158	-1174.41668	146.29083	0.46560	21.11884
Y = A + B * LOG(X)	-28.06523	10.56554	117.61366	0.57035	19.09021
$Y = A * X^B$	1.59940	0.48735	139.88648	0.48899	20.78234
Y = X/(A + B * X)	2.61123	0.04957	250.30750	0.00562	28.18276

EQUATION Y = A + B * LOG(X) HAS MAXIMUM R-SQUARE

EQUATION Y = A + B * LOG(X) HAS MINIMUM (MAXIMUM ABSOLUTE RESIDUAL)

TABLE H.6. RESULTS OF REGRESSION ANALYSIS ON RETROFIT SH?DHW DESIGN DATA

EQUATION	A	B	RES ERROR	R-SQUARE	MAX DEVIATION
Y = A * X	0.02874		36.12858	-3.51687	7.24064
Y = A + B * X	6.65269	0.00240	7.86587	0.01677	3.95928
Y = A * EXP(B * X)	6.10041	0.00046	8.19804	-0.02475	3.62513
Y = 1/(A + B * X)	0.18083	-0.00009	9.42976	-0.17872	4.19866
Y = A + B/X	7.16032	-15.56387	7.99268	0.00091	4.03872
Y = A + B * LOG(X)	5.68436	0.27825	7.95346	0.00582	4.03444
$Y = A * X^{B}$	5.40706	0.03957	8.29414	-0.03677	3.55170
Y = X/(A + B * X)	-1.30298	0.16148	9.73341	-0.21668	4.04422

EQUATION Y = A + B * LOG(X) HAS MAXIMUM R-SQUARE

EQUATION Y = A + B * LOG(X) HAS MINIMUM (MAXIMUM ABSOLUTE RESIDUAL)

FIGURE H.3 PLOT OF BEST FIT EQUATION FOR NEW DHW DESIGN DATA

PARAMETERS

Y = A + B * X

A =
3.63081657338

B =
0.229235841002

R-Square =
0.717774131165

RES ERROR
145.1993298

MAX(ABS(RESIDUAL))
18.0303161465

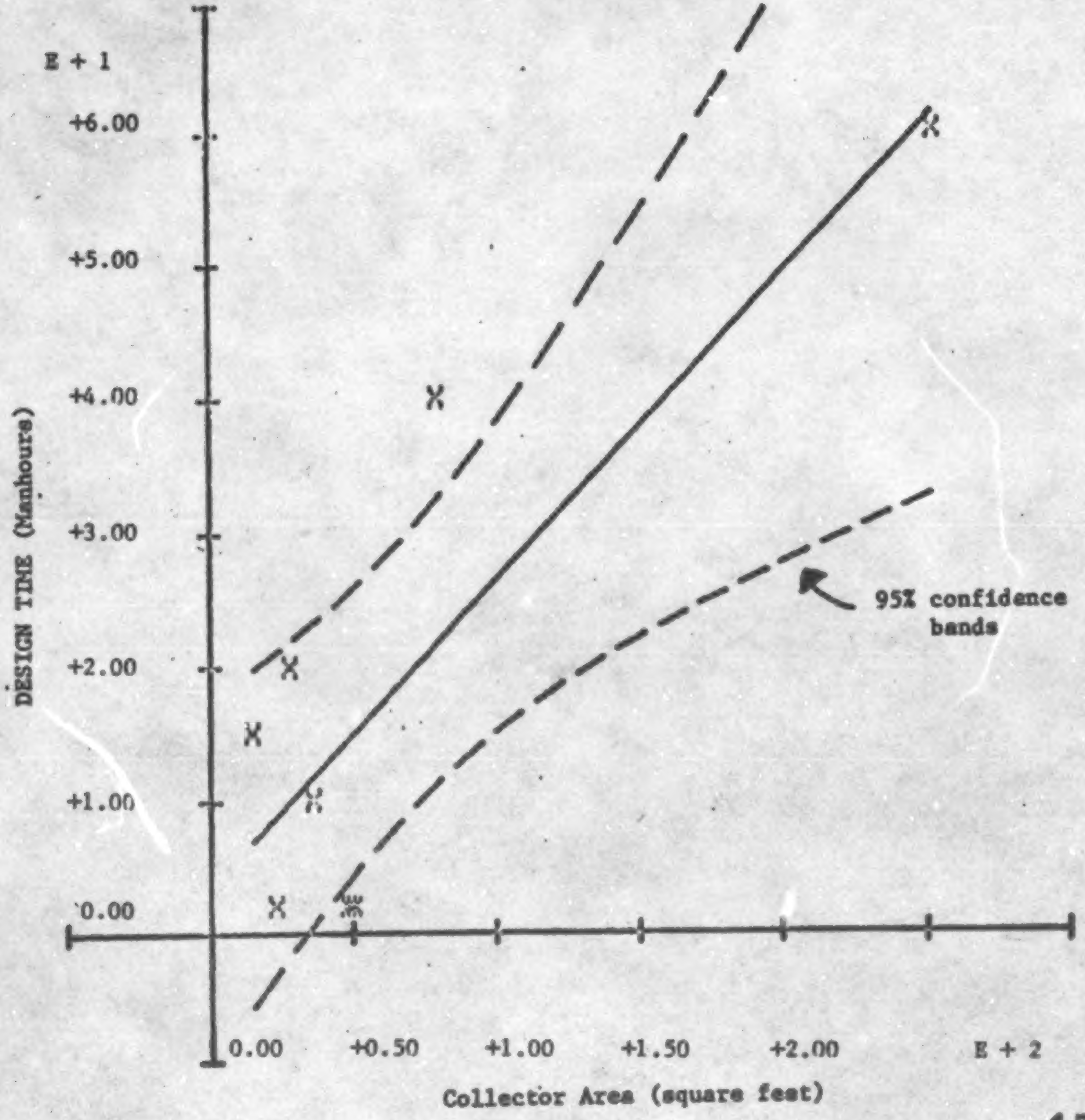


FIGURE H.4. PLOT OF BEST FIT EQUATION FOR NEW SH/DHW DESIGN DATA

PARAMETERS

$Y = A + B * X$

A =
28.2884867493

B =
0.0401097793813

R-SQUARE =
0.559493802356

RES ERROR
942.593609651

MAX(ABS(RESIDUAL))
58.8763839486

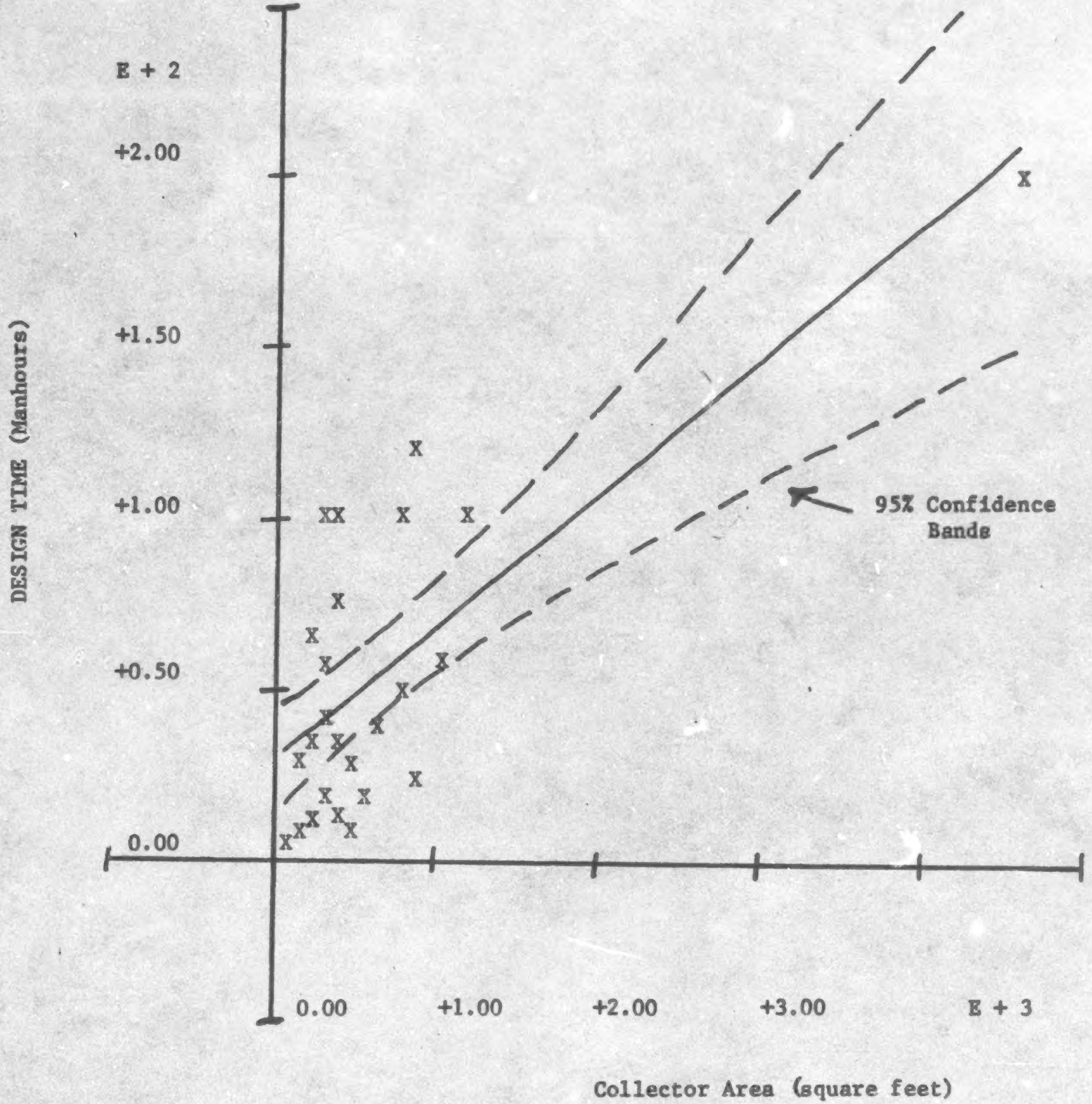


FIGURE H.5 PLOT OF BEST FIT EQUATION FOR RETROFIT DHW DESIGN DATA

PARAMETERS

Y = A + B * LOG(X)

A =
-28.0652290566

B =
10.565544804

R-SQUARE =
0.570354824341

RES ERROR
117.613661895

MAX(ABS(RESIDUAL))
19.0902079075

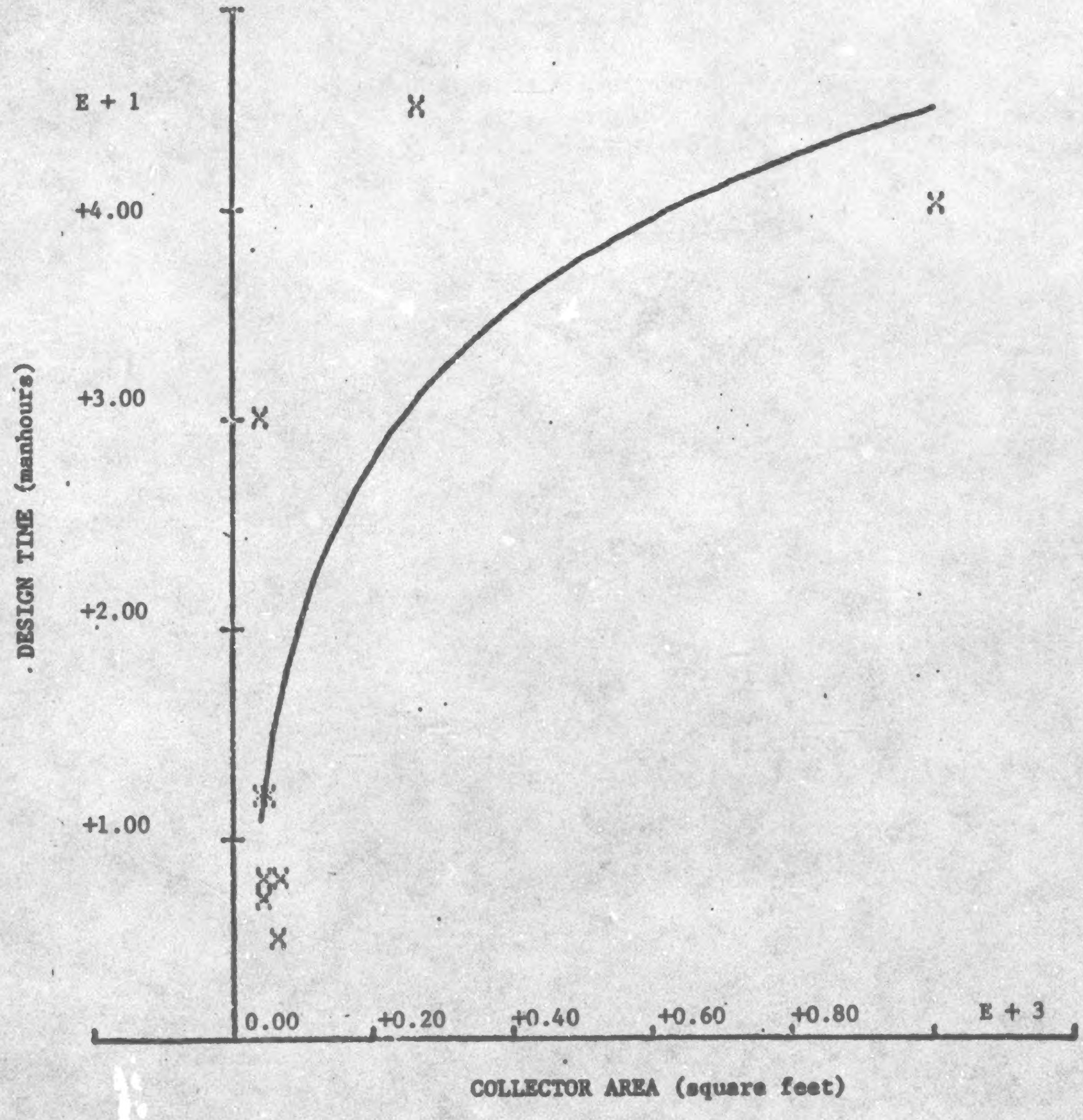


FIGURE H.6 PLOT OF LINEAR FIT EQUATION FOR RETROFIT DHW DESIGN DATA

PARAMETERS

```
Y = A + B * X

A =
  12.7767860249

B =
  0.0322236219184

R-SQUARE =
  0.432737494857

RES ERROR
  155.28585941

MAX(ABS(RESIDUAL))
  23.7161777887
```

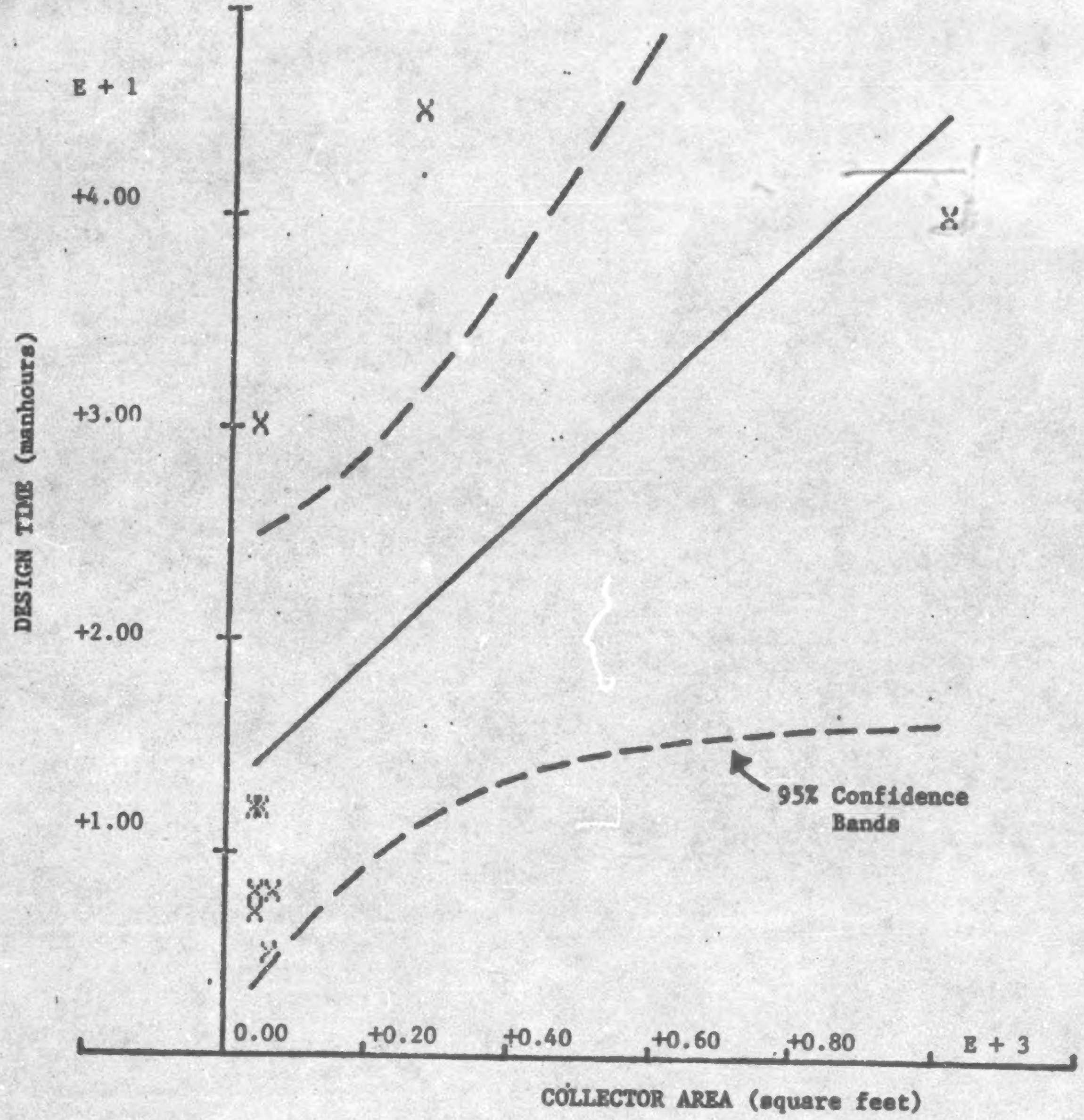


FIGURE H.7. PLOT OF BEST FIT EQUATION FOR RETROFIT SH/DHW DESIGN DATA

PARAMETERS

Y = A + B * X

A =
6.65268718322

B =
0.00239526080541

R-SQUARE =
0.0167668256379

RES ERROR
7.8658653949

MAX(ABS(RESIDUAL))
3.95029056631

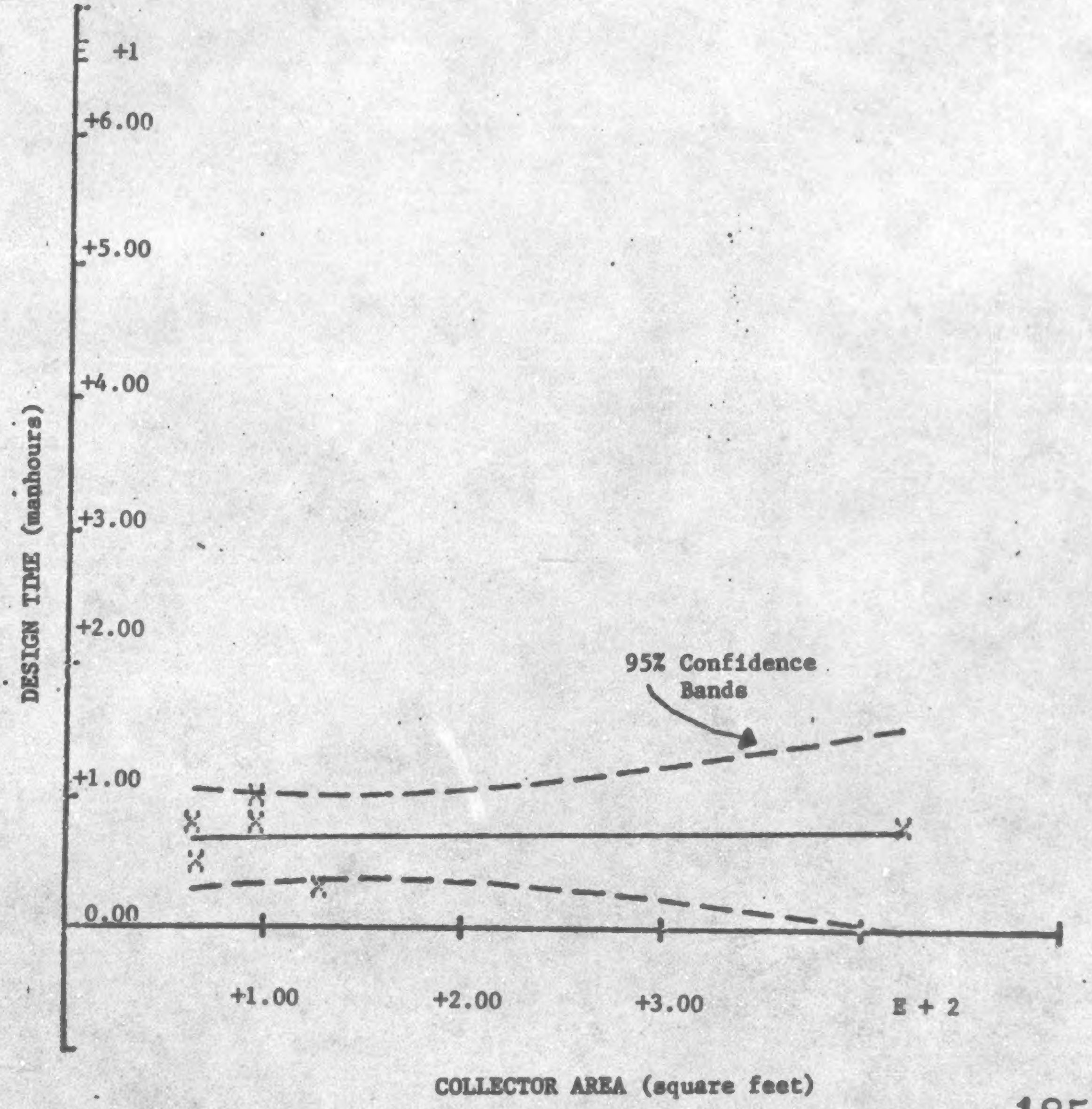


TABLE H.7

RESPONSE DATA ON INSTALLATION TIME VERSUS COLLECTOR AREA

NEW				RETROFIT			
DHW		SH/DHW		DHW		SH/DHW	
COLLECTOR AREA (x)	INSTALLATION TIME (y)	COLLECTOR AREA (x)	INSTALLATION TIME (y)	COLLECTOR AREA (x)	INSTALLATION TIME (y)	COLLECTOR AREA (x)	INSTALLATION TIME (y)
23	22	480	300	1000	900	64	24
48	16	4500	1750	40	26	96	24
50	24	720	260	50	24	420	120
252	400	148	42	40	48	128	120
60	32	176	200	43	54	240	80
15	38	576	280	68	90	320	160
48	32	360	80	44	64	66	30
48	6	724	125	65	48	96	46
36	20	468	360	40	26	470	100
		740	225	50	58	96	20
		864	200	64	96	128	120
		64	24	80	40		
		128	32				
		840	320				
		429	280				
		630	240				
		240	75				
		400	200				
		276	150				
		384	64				
		225	140				
		468	124				
		700	180				
		294	80				
		42	25				
		180	200				
		800	80				
		373	75				
		360	180				
		1260	160				
		432	80				
		360	56				
		256	28				

TABLE II.8.

RESULTS OF REGRESSION ANALYSIS ON NEW DHW INSTALLATION DATA

EQUATION	A	B	RES ERROR	R-SQUARE	MAX DEVIATION
$Y = A * X$	1.39822		1979.17658	0.89097	51.89331
$Y = A + B * X$	-42.35854	1.70785	729.01199	0.95984	46.74080
$Y = A * EXP(B * X)$	12.31047	0.01340	316.94330	0.98254	39.31952
$Y = 1/(A + B * X)$	0.06701	-0.00025	6144.83362	0.66148	205.48958
$Y = A + B/X$	158.68697	-3392.99688	13919.84883	0.23315	254.77730
$Y = A + B * LOG(X)$	-448.69803	135.04930	5644.03788	0.68907	112.97775
$Y = A * X^B$	0.59113	1.01967	7992.57195	0.55969	233.91937
$Y = X/(A + B * X)$	0.12699	0.04811	20663.64726	-0.13837	379.42795

EQUATION Y = A + B * LOG(X) HAS MAXIMUM R-SQUARE

EQUATION Y = A + B * LOG(X) HAS MINIMUM (MAXIMUM ABSOLUTE RESIDUAL)

TABLE H.9.

RESULTS OF REGRESSION ANALYSIS ON NEW SH/DHW INSTALLATION DATE

EQUATION	A	B	RES ERROR	R-SQUARE	MAX DEVIATION
Y = A * X	0.35933		10876.60710	0.87799	292.75855
Y = A + B * X	-8.55312	0.36490	10827.74484	0.97854	291.21509
Y = A * EXP(B * X)	81.68933	0.00078	42131.79116	0.52738	1013.52783
Y = 1/(A + B * X)	0.01453	-0.00001	124600.70485	-0.39774	1857.07839
Y = A + B/X	269.24568	-18109.29517	82083.60696	0.07921	1484.77861
Y = A + B * LOG(X)	-1088.58784	216.10105	53448.24005	0.40043	1020.78193
Y = A * X^{B}	1.07497	0.80115	30628.46473	0.65642	841.83980
Y = X/(A + B * X)	1.86759	0.00440	85631.21444	0.03941	1542.20979

EQUATION Y = A + B * LOG(X) HAS MAXIMUM R-SQUARE

EQUATION Y = A + B * LOG(X) HAS MINIMUM (MAXIMUM ABSOLUTE RESIDUAL)

TABLE H.10.

RESULTS OF REGRESSION ANALYSIS ON RETROFIT DHW INSTALLATION DATA

EQUATION	A	B	RES ERROR	R-SQUARE	MAX DEVIATION
Y = A * X	0.30076		562.11034	0.99160	38.35136
Y = A + B * X	2.00568	0.09768	559.26020	0.99166	36.54253
Y = A * EXP(B * X)	36.70688	0.00323	721.37552	0.98922	50.87653
Y = 1/(A + B * X)	0.02773	-0.00003	805573.04540	-11.03309	2836.85786
Y = A + B/X	634.77758	-28026.20652	24053.35507	0.64071	293.24862
Y = A + B * LOG(X)	-1008.37490	269.4285	3925.18782	0.94137	132.26812
$Y = A * X^{B}$	0.79510	1.01626	490.65626	0.99118	41.55255
Y = X/(A + B * X)	1.38446	-0.00130	11322888.51070	-169.13339	10640.60126

EQUATION Y = A + B * LOG(X) HAS MAXIMUM R-SQUARE

EQUATION Y = A + B * LOG(X) HAS MINIMUM (MAXIMUM ABSOLUTE RESIDUAL)

TABLE H.11.

RESULTS OF REGRESSION ANALYSIS ON RETROFIT SH/DHW INSTALLATION DATA

EQUATION	A	B	RES ERROR	R-SQUARE	MAX DEVIATION
Y = A * X	0.33645		2098.38468	0.24489	76.93404
Y = A + B * X	34.08833	0.22082	1608.36803	0.42122	57.64631
Y = A * EXP(B * X)	29.94871	0.00358	2226.16347	0.19891	72.61888
Y = 1/(A + B * X)	0.03602	-0.00007	22272.96753	-7.01500	418.67745
Y = A + B/X	143.18698	-8172.63363	1063.07997	0.61745	42.35250
Y = A + B * LOG(X)	-181.40716	51.45140	1247.51848	0.55108	51.76341
$Y = A * X^{B}$	0.92829	0.83035	1740.56022	0.37365	67.83171
Y = X/(A + B * X)	2.64330	0.00052	1992.76110	0.28290	72.76263

EQUATION Y = A + B * LOG(X) HAS MAXIMUM R-SQUARE

EQUATION Y = A + B * LOG(X) HAS MINIMUM (MAXIMUM ABSOLUTE RESIDUAL)

(and linear fit, if required) are shown.

The installation time for a typical DHW system was 44 manhours (for both, new and retrofit), while the installation time for a typical SH/DHW system was 183 manhours (new) and 121 manhours (retrofit). The installation time for a typical DHW was relatively the same, but varied considerably for the typical SH/DHW. This may be because of the type of construction.

In preparing the task analysis, it was learned that maintenance time, similar to design time, should be the same for systems with small variations in the total collector area. The statistical analysis supported this conclusion. The hypothesis that the maintenance time is independent of total collector area was accepted to insufficient evidence for dependence. (Statistical t-tests, sample size Z-tests and the variability of data explained). Insufficient information was available on the maintenance time of retrofitted SH/DHW systems. The response data on maintenance time versus collector area is listed in Table H.12. The results of regression analysis on these data are shown in Tables H.13, H.14 and H.15, and the plots of best fit and linear fit are shown in Figures H.12, H.13 and H.14. The maintenance times for typical DHW systems were 7 manhours (new) and 2 manhours (retrofit), and for typical SH/DHW systems it is 9 manhours.

Little information was available on the repair time of a system because of the random nature of the repair problems encountered and the inability to predict, in advance, the time requirement for that problem. Furthermore, no records of repair, at present, have been kept by solar contractors. Limited data on repair time are available for new SH/DHW systems and the analysis predicted approximately 7 manhours were required for the repair of new typical SH/DHW system.

It is evident from this statistical analysis that the solar energy industry is not mature enough at present to provide a statistically large

TABLE H. 12

RESPONSE DATA ON MAINTENANCE TIME VERSUS TOTAL COLLECTOR AREA

NEW				RETROFIT			
DHW		SH/DHW		DHW		SH/DHW	
COLLECTOR AREA (x)	MAINTENANCE TIME (y)	COLLECTOR AREA (x)	MAINTENANCE TIME (y)	COLLECTOR AREA (x)	MAINTENANCE TIME (y)	COLLECTOR AREA (x)	MAINTENANCE TIME (y)
23	1	480	5	1000	120		
48	2	1053	8	40	1	NO DATA	AVAILABLE
80	8	720	10	50	1		
50	2	148	4	40	1		
252	28	176	3	50	3		
		576	10	64	2		
		1200	40	80	1		
		864	20				
		429	8				
		630	20				
		400	5				
		276	5				
		225	12				
		468	10				
		700	4				
		294	16				
		304	24				
		42	2				
		378	4				
		368	3				
		720	30				
		432	2				

TABLE H.13.

RESULTS OF REGRESSIONAL ANALYSIS ON NEW DHW MAINTENANCE DATA

EQUATION	A	B	RES ERROR	R-SQUARE	MAX DEVIATION
Y = A * X	0.07841		3.49518	0.95891	1.92028
Y = A + B * X	-1.10791	0.08508	2.56537	0.96984	2.30181
Y = A * EXP(B * X)	1.24911	0.01181	14.52654	0.82923	4.78727
Y = 1/(A + B * X)	0.78645	-0.00300	560.57081	-5.58978	40.58309
Y = A + B/X	15.00279	-416.88840	34.95154	0.58913	6.65153
Y = A + B * LOG(X)	-29.29739	8.61428	7.91835	0.90692	3.27737
$Y = A * X^{B}$	0.01419	1.33156	5.36150	0.93697	3.14553
Y = X/(A + B * X)	25.21952	-0.07332	105.69798	-0.24253	17.37806

EQUATION Y = A + B * LOG(X) HAS MAXIMUM R-SQUARE

EQUATION Y = A + B * LOG(X) HAS MINIMUM (MAXIMUM ABSOLUTE RESIDUAL)

TABLE H.14.

RESULTS OF REGRESSION ANALYSIS ON NEW SH/DHW MAINTENANCE DATA

EQUATION	A	B	RES ERROR	R-SQUARE	MAX DEVIATION
Y = A * X	0.02190		70.79189	0.33360	17.34104
Y = A + B * X	1.23639	0.02003	70.37220	0.33755	16.67524
Y = A * EXP(B * X)	3.40520	0.00167	72.36314	0.31880	18.63975
Y = 1/(A + B * X)	0.29963	-0.00025	2320.48706	-20.84408	211.53856
Y = A + B/X	13.48087	-659.02347	95.87778	0.09745	27.06832
Y = A + B * LOG(X)	-28.18779	6.55753	81.40982	0.23364	21.69442
$Y = A * X^{B}$	0.15620	0.65186	85.38179	0.19625	24.11865
Y = X/(A + B * X)	17.14464	0.11685	123.58803	-0.16341	32.37429

EQUATION Y = A + B * LOG(X) HAS MAXIMUM R-SQUARE

EQUATION Y = A + B * LOG(X) HAS MINIMUM (MAXIMUM ABSOLUTE RESIDUAL)

TABLE H.15.

RESULTS OF REGRESSION ANALYSIS ON RETROFIT DHW MAINTENANCE DATA

EQUATION	A	B	RES ERROR	R-SQUARE	MAX DEVIATION
Y = A * X	0.11828		33.21542	0.38621	8.46214
Y = A + B * X	-5.22776	0.12507	34.35993	0.99919	3.77794
Y = A * EXP(B * X)	1.04411	0.00474	0.76636	0.99968	1.67658
Y = 1/(A + B * X)	0.85139	-0.00084	117.26917	0.95130	24.13392
Y = A + B/X	94.72529	-4483.33281	702.88335	0.70810	37.68363
Y = A + B * LOG(X)	-149.19312	38.28169	112.48147	0.95329	17.55827
$Y = A * X^{B}$	0.00426	1.46113	58.52793	0.97569	16.94528
Y = X/(A + B * X)	34.40554	0.10616	2549.44986	-0.05877	112.88579

EQUATION Y = A* EXP(B * X) HAS MAXIMUM R-SQUARE

EQUATION Y = A* EXP(B * X) HAS MINIMUM (MAXIMUM ABSOLUTE RESIDUAL)

Figure H.12
PLOT OF BEST FIT EQUATION FOR RETROFIT SH/DHW INSTALLATION DATA

Parameters

Y = A + B/X

A =
143.186975172

B =
-8172.63362809

R-SQUARE =
0.617447015811

RES ERROR
1063.07996552

MAX(ABS(RESIDUAL))
42.3525039162

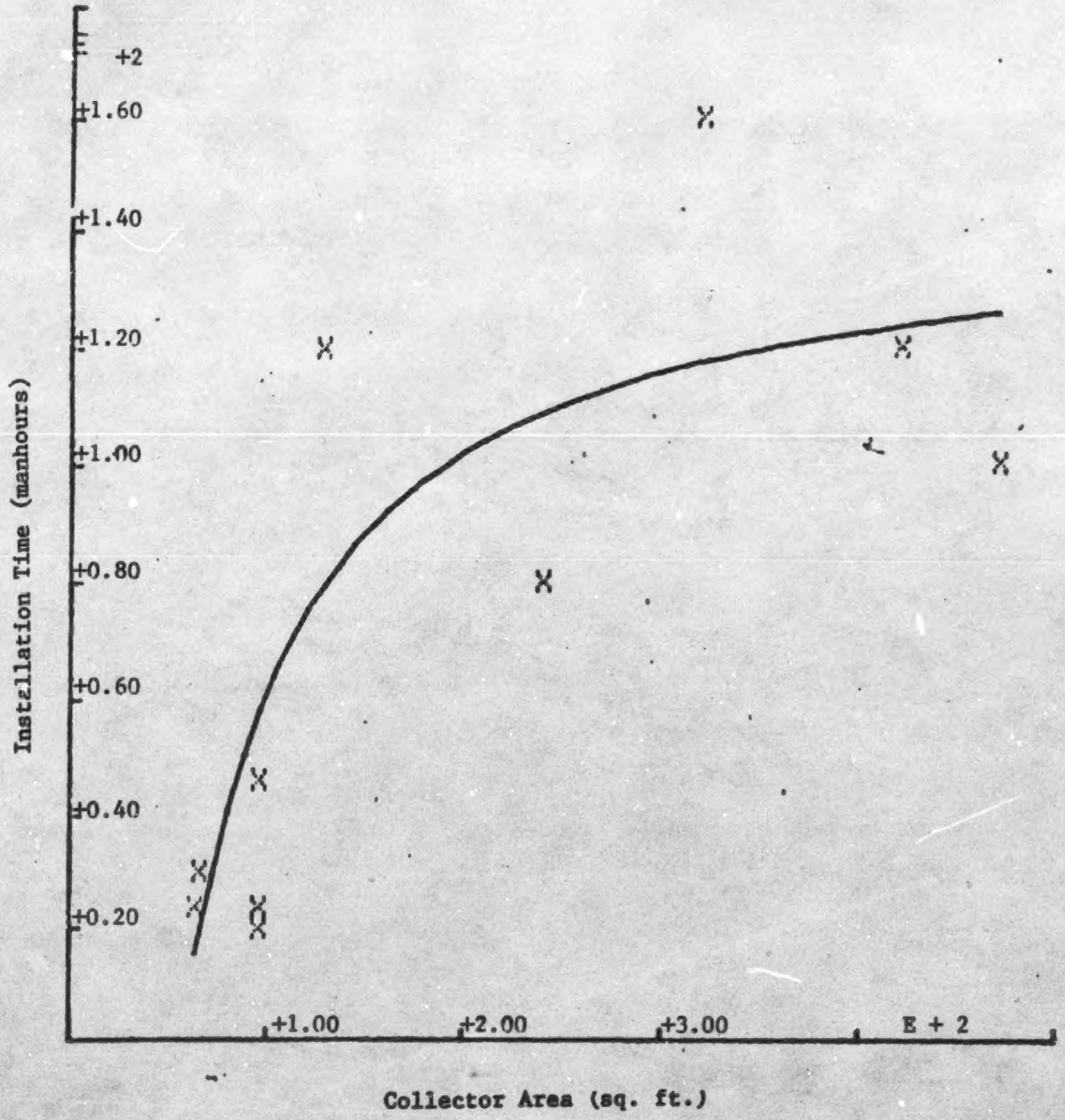


Figure H.13

PLOT OF LINEAR FIT EQUATION FOR RETROFIT SH/DHW INSTALLATION DATA

Parameters

Y = A + B * X

A =
34.0883326208

B =
0.220823136145

R-SQUARE =
0.421223230488

RES' ERROR
1608.3680264

MAX(ABS(RESIDUAL))
57.6463059527

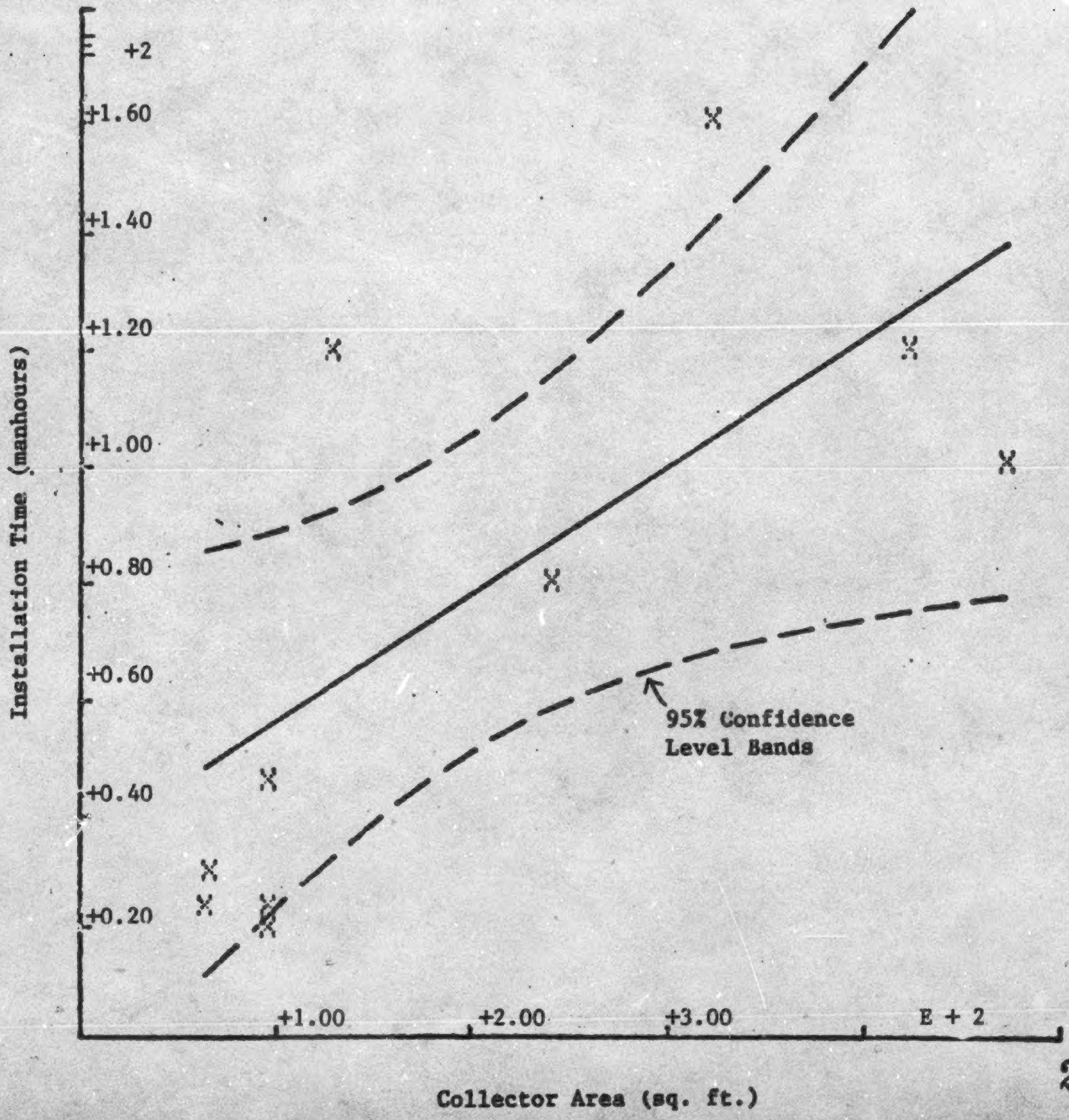


FIGURE H.14 PLOT OF BEST FIT EQUATION FOR NEW DHW MAINTENANCE DATA

PARAMETERS

Y = A + B * X

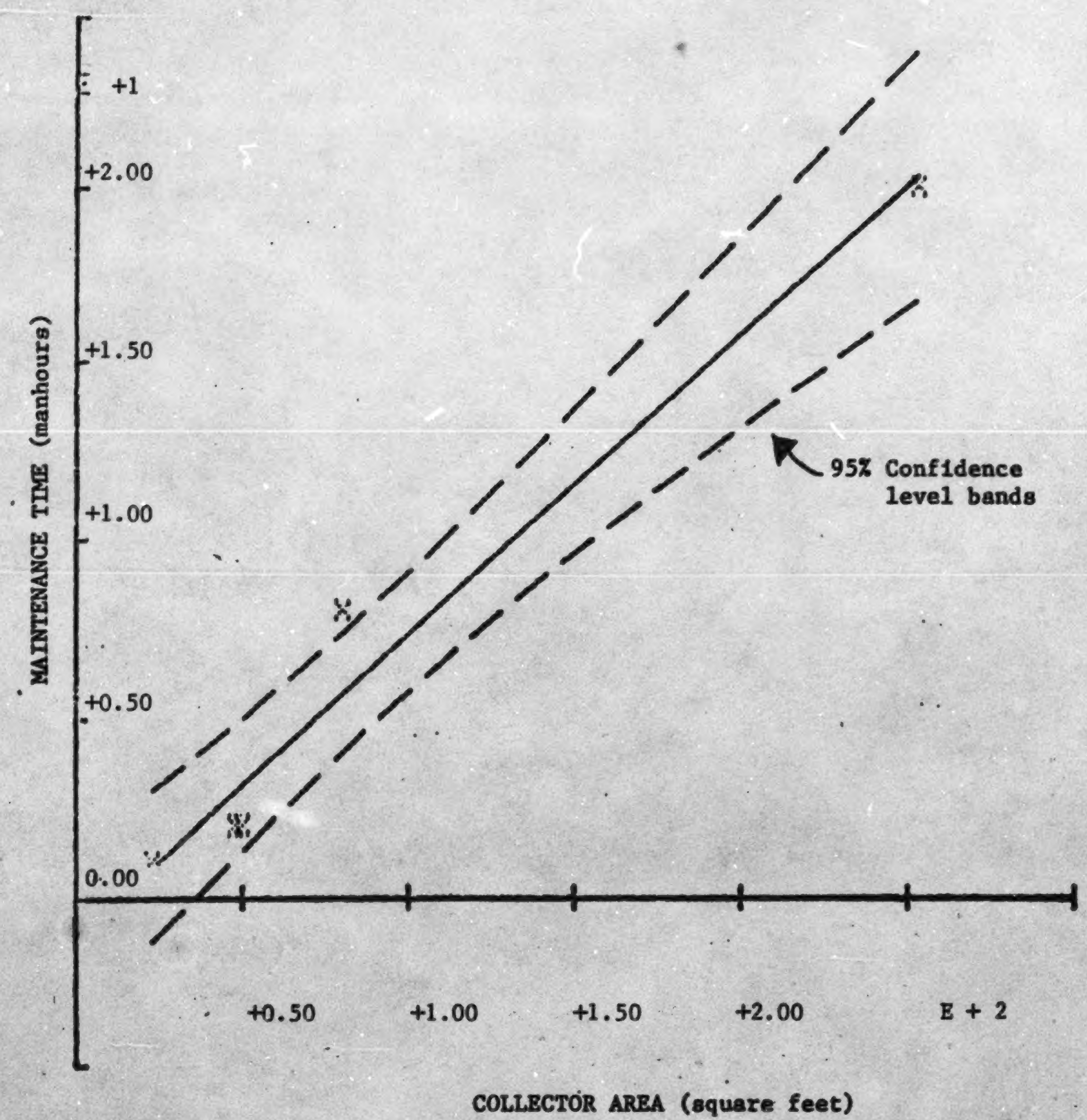
A =
-1.10790988209

B =
0.0850762680142

R-SQUARZ =
0.969842785686

RES ERROR
2.[illegible]6537369767

MAX(ABS(RESIDUAL))
2.30180844095



industry is not mature enough at present to provide a statistically large sample so that accurate predictions of the time requirements for each stage can be made. However, certain conclusions can be made:

1. The design time can be considered independent of total collector area for a given generic type of the system.
2. The installation time is a direct function of the total collector area and varies significantly among different types of construction with the same collector area.
3. The maintenance time depends on the type (DHW or SH/DHW) of system rather than the size.

It should be noted that the results derived above are not independent of learning curve effects, climatological variations, effects of building codes, and other relevant factors. A regional statistical analysis was not possible from the sample collected.

APPENDIX I

PERSONAL INTERVIEWS, SOLAR MANUFACTURERS/DISTRIBUTERS/DEALERS

This appendix contains information regarding the personal interviews that were held with representatives of the solar industry. Questions were asked regarding installation times, required skills, sequences of crafts, etc. A statistical treatment of responses is given and the industry representatives and their affiliations are listed.

MANUFACTURERS/DISTRIBUTORS/DEALERS INTERVIEWED

Acurex Corp.
415/964-3200
Contact: Ed Rossiter

Albuquerque Weatern Industries
505/344-7224
Contact: Lloyd Hart

Alten Assoc.
415/969-6474
Contact: Bob Roller

American Appliance Mfg.
213/829-1755
Contact: Shean McCoy

American Solar Heat Corp.
203/792-0077
Contact:

American Heliothermal Corp.
303/778-0650
Contact: Secretary

Chemical Processor
813/822-3689
Contact: Ed Hudock

Cole Solar Systems, Inc.
512/444-2565
Contact: Warren Cole

CSI Solar Systems Division
813/577-4228
Contact: Roy Sallen

Day Star Corp.
617/272-8460
Contact: Mike Bullenges

Energy Converters
615/624-2608
Contact: David Burrows

Falbel Energy Systems
203/357-0626
Contact: Jim Love

Hamilton Research
213/241-3057
Contact: R. A. Hamilton

Largo Solar Systems
305/583-8090
Contact: Ron Hannivig

Lennox
515/754-4011
Contact: Ted Gilles

O.E.M. Products, Inc.
813/247-5947
Contact: D.W. Barlow, Sr.

Pacific Sun, Inc.
415/328-4588
Contact: Harry Whitehouse

R-M Products
303/825-0203
Contact: Steve Piro

Sol-Aire
415/632-5400
Contact: Bruce Springer

Solar Applications, Inc.
714/292-1857
Contact: Frank Ames

MANUFACTURERS/DISTRIBUTORS/DEALERS
(continued)

Solar Comfort Systems
305/842-8935
Contact: Don Kazimir

Solar Dynamics, Inc.
305/688-4393
Contact: Ed Jester

Solar Energy Products, Inc.
Contact: Chris Bisset

Solar Energy Systems, N.J.
609/424-
Contact: John Wood

Solar Innovations
813/688-8373
Contact: Joe Conrad

Solar King
817/776-3860
Contact: Thomas Bennett

Solar Sun
513/241-4200
Contact: Sal Santor

Solarcoa
213/426-7655
Contact: Ken Parker

SOLAR MANUFACTURER/DISTRIBUTOR/DEALER INTERVIEWS CONCERNING:

INSTALLATION TIME AND TRAINING PROGRAM

Manufacturers of solar water and space heating systems and the distributors/dealerships which install them constitute a large portion of solar industry in the United States. Phone interviews with a representative portion of these persons were conducted to determine the installation time and the training programs used by this part of the industry. Twenty-nine (29) of these manufacturers and distributors/dealerships were contacted, and the results are contained in the following report. The list of interviewees is attached after this report.

First, a few observations on the 29 interviewed are appropriate. The companies contacted varied from large-scale manufacturers to small operations which install systems as a sideline. In general, the larger manufacturers had better training programs and gave a more complete response to the questionnaire. The responses to the questions concerning water heating systems were far more complete than the responses to the space heating questions, due to the small percentage of dealers in this area, and the multitude of parameters which affected conscientious responses.

A. INSTALLATION TIME

1. What is the total installation time required (man-hours) for installation?

Water heating: 89.7% of the companies responded, as shown in Figure 1. Notice the clustering at 16 and 24 hours. This is due to the fact a crew of 2 or 3 usually install the system in one day. Figure 2 redepicts the data in Figure 1 and indicates the vast majority of the installations require between 15 and 24 man hours.

Hrs.

	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	>32
%	4	8	0	4	4	8	0	28	0	8	0	24	0	0	4	4	4

Figure 1. Man-hours required for hot water system installation.

Hrs.

	0-14	15-24	>25
%	28	60	12

Figure 2. Grouped responses for hot water installation time.

Space heating: 31.0% of the companies responded, as shown in Figure 3. There are no trends in these figures due to the ambiguity (lack of specification of size) of the question.

Hrs.

	20	40	60	80	100	120	140	160	180	200	450
%	1.25	0	25	0	25	0	0	0	0	12.5	25

Figure 3. Man-hours required for space heating system installation.

2. What kind of skills or crafts are used?

Water heating: 86.2% responded, as shown in Figure 4. It should be noted that most of these skills are performed by 2 or 3 men. A qualified or licensed plumber is almost certainly involved.

Space heating: 6.9% responded, as shown in Figure 4. The response shows plumbing to be an essential part of the installation, with the other crafts being used to a greater extent than for water heating.

% W.H.	Skill	% S.H.
96	Plumbing	100
56	Electrical	80
24	Sheet Metal	80
48	Carpentry	80
4	Refrigeration	

Figure 4. Skills/crafts needed for installation of water and space heating systems.

3. How many man-hours does each craft spend on the job?

Water heating: 51.7% responded, as shown in Figure 5. The amount of plumbing required depends on the location of the collectors with respect to the water heater. The amount of carpentry used, if any, depended on whether the job was a retrofit or new installation, and the number of panels. The electrical work consists only of wiring the pump (and other incidentals, if any).

Space heating: there was insufficient response to the question.

Skill	W.H. Hrs.										S.H. % (2 cases)	
	3	6	9	12	15	18	21	24	27	30		
Elec.	86	14									5	11
Plumb.	20	7	13	13	13	7	7	7	7	7		81
Hvac												
Sheet Mtl.												8
Carpentry	25	25	50									

Figure 5. Man-hours each craft spends on-the-job.

4. In what sequence are the crafts used?

The sequence of the crafts was the same for water and space heating. Generally, the plumbers were used followed by the electrician. In conjuction with the plumbing was the carpentry work. These crafts alternated the sequence depending on whether the collector plates were installed before or after the plumbing, and whether the installation was new or retrofit.

5. How many men are on a crew?

75.9% responded, as shown in Figure 6. The vast majority of the crews are two men.

	# of Men			
	1	2	3	4
%	0	77	14	9

Figure 6. Number of men on a crew.

6. About how much design time is required for each job?

62.1% responded, as shown in Figure 7. The lower end design times are the water heating design times and the computer designs. The figures above 7 hours, generally represent the space heating design requirement.

	Design Time (Hours)									
	1	2	3	4	5	6	7	8	9-50	50-100
%	30	27	0	14	0	0	0	7	14	14

Figure 7. Man-hours needed for design of water and space heating systems.

7. Who does the design?

69% responded, as shown in Figure 8. The obvious discrepency in the percentages is due to the fact that most of the designs are done by an engineer or a technician, sometimes with computer assistance.

	Engr.	Tech.	Computer
%	75	25	35

Figure 8. Person doing design.

8. Do you have a trained technician or foreman who is responsible for the system check and start-up?

65.5% responded, as shown in Figure 9. Self-explanatory.

	Yes	No
%	84	16

Figure 9. Trained technician/foreman responsible for system check and start-up.

9. What are the estimated maintenance - repair man-hours/year?

31% responded, as shown in Figure 10. Over 2/3 of the response listed the only maintenance as less than 2 man-hours, usually in conversion from summer/winter cycles or in pump repair.

	0-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16	17-18	19-20
%	67			11	11					11

Figure 10. Man-hours per year for maintenance.

B. TRAINING PROGRAM

1. Do you have distributors and dealers?

93.1% responded, as shown in Figure 11. Self-explanatory.

	Yes	No
%	96	4

Figure 11. Manufacturers with distributors/dealers.

2. What are their capabilities when finished?

72.4% responded, as shown in Figure 12. Most of those trained can install systems only. The minority can both install and do some limited design, i.e., fill out specification sheets.

	Install	Install & Design
%	55	45

Figure 12. Capabilities of trained distributors/dealers.

3. How long are the distributors (dealer) trained?

62.1% responded, as shown in Figure 13. The vast majority of the training programs are 1 week or less. Most of the training programs are 2 days or less. Personnel trained less than two days were qualified to install systems only.

# of Days

	1	2	3	4	5	6	7	8	9	10
%	27	30	14	6	18	0	0	0	0	6

Figure 13. Length of distributor/dealer training period.

4. Who are your distributors/dealers?

65.5% responded, as shown in Figure 14. The majority of the distributors are plumbers and HVAC personnel.

	Hvac	Plumbers	Solar	Mech. Cont.	Distributors
%	47	68	20	5	5

Figure 14. Background for distributor/dealers.

5. Do you supply design data to the dealers?

51.7% responded, as shown in Figure 15. Self-explanatory.

	Yes	No
%	73	27

Figure 15. Manufacturer s supplying design data to dealers.

6. Would a trained solar worker from a vocational school be a valuable man to your company?

55.2% responded unanimously, as shown in Figure 16.

	Yes	No
%	100	0

Figure 16. Manufacturers desiring a trained solar worker.

For installation?

44.9% response. Unanimously yes

For trouble-shooting?

42.8% response. 54% yes; 46% no. The fraction which responded negatively felt a trouble-shooter should have experience in solar water and space heating as well as vocational training.

APPENDIX J

CONTRACTOR SURVEY FORM

This appendix contains a sample of the form that was sent to contractors soliciting response to questions concerning their experience with solar systems.

NAVARRO COLLEGE

Highway 31 West
Corsicana, Texas 75110

Phone 214-874-6501

Dear Sir:

Navarro College has a grant from the U.S. Energy Research and Development Administration (ERDA) to "Assess the Need for Developing and Implementing Technical and Skilled Worker Training for the Solar Energy Industry". As part of this study we need to forecast the manpower requirements for solar technicians.

You have been identified as one who has experience in designing and/or installing solar systems. We are relying on your experience and asking for your time in completing the attached brief questionnaire to estimate manpower requirements for the design, installation, maintenance, and repair of solar systems.

You are one of few who is qualified to provide the necessary information. You, by your experience with solar equipment, can affect the future progress of solar energy utilization in our country. Please help us in our efforts to provide quality training in this new and exciting field.

Thank you.

Sincerely,

H. J. Gibson

Harold J. Gibson
Occupational Analyst

HJG:sg

INFORMATION

NAME________________________________TITLE____________________

COMPANY____

ADDRESS____
(Street)

____
(City) (State) (Zip)

DATE________________________ PHONE ( )________________________

I. Under each category, please check the item(s) which best reflects the system you have installed.

1. **INSTALLATION COMPLETED**

DATE________________________

2. **INSTALLATION**

___Retro-fit

___New Construction

3. **SECTOR**

___Residential

___Commercial

___Industrial

___Agricultural

4. **APPLICATION**

___Domestic Hot Water

___Space Heating

___Space Cooling

___Process Heat

___Other

5. **COLLECTOR**

___Flat Plate

___Concentrating (Tracking)

___Concentrating (Stationary)

6. **FLUID**

___Air

___Liquid

II. Please answer all questions below for the system you have installed.

1. Collector manufacturer________________________________

2. Number of collectors______________

3. Total collector area______________

4. Approximate area of building______________

FOR DESIGN OF SYSTEM:

5. Total man-hours required______________

FOR INSTALLATION OF SYSTEM:

6. Total number of workers involved in installation______________

7. Total man-hours required______________

FOR ROUTINE MAINTENANCE OF SYSTEM:

8. Total man-hours required per year______________

FOR REPAIR OF SYSTEM:

9. Total man-hours required per year______________

III. How many solar installations have you completed?______________

IV. How many persons in your firm are performing solar related work?

____

V. Would you hire a solar designer or installer if such a trained technician were available? ______________ If no, explain.

VI. COMMENTS: (Use Back)

APPENDIX K

TASK INVENTORY FORM

This section contains a sample of the form that was sent to contractors soliciting response to questions regarding tasks to be performed by solar workers. This form was later used by the Task Analysis Consultants in completing the task inventory.

For purposes of this report, the type of tradesman for each task was indicated by our panel of experts. This denotation was made as to the type of tradesman who traditionally or normally would perform that task. The symbols are as follows:

C - Carpenter
E - Electrician
H - HVAC man
P - Plumber
S - Solar person
SM - Sheet metal man
X - Other (Homeowner, General Laborer, and Commercial Insulator)

For simplicity, the times given on this Task Inventory are in minutes rather than in hours and minutes as specified in the instructions.

DESIGN STAGE	No. Persons Required Type Person	Time Required (Minutes)	Learning Difficulty
A. Calculate Hot Water Load			
1. Determine monthly average ground water temperature	1 - S	15 minutes total	1
2. Determine design hot water temperature	1 - S		1
3. Determine hot water requirement for persons	1 - S		1
4. Determine hot water requirement for applicances	1 - S		1
5. Determine BTU requirement of monthly hot water load	1 - S		1
B. Calculate Space Heating Load			
1. Determine inside and outside design temperatures and design wind speed	1 - H	0	1
2. Determine U-values for structure components	1 - H	60	2
3. Determine areas of structure components	1 - H	60	1
4. Determine infiltration of structure	1 - H	15	2
5. Calculate total heat loss under design conditions in BTU/hr	1 - H	15	1
6. Divide design heat loss by design temperature differential and multiply by 24 to obtain heat loss in BTU/DD	1 - H	10	1
7. Determine monthly heating degree days	1 - H	0	1
8. Determine degree day correction factor for outside design temperature	1 - H	60	2
9. Calculate monthly BTU requirement for space heating load	1 - H	5	1

DESIGN STAGE	No. Persons Required Type Person	Time Required (Minutes)	Learning Difficulty
C. Calculate Space Cooling Load			
1. Determine inside and outside design temperatures, latitude, and daily temperature range	1 - H	10	1
2. Determine equivalent temperature differences	1 - H	15	1
3. Determine U-Values for structure components	1 - H	60	2
4. Determine areas of structure components	1 - H	60	1
5. Determine window shading	1 - H	60	2
6. Determine transmittance of windows	1 - H	0	1
7. Calculate heat gain through windows	1 - H	30	2
8. Calculate internal heat gains	1 - H	20	1
9. Calculate total heat gains under design conditions	1 - H	15	1
10. Divide design heat gain by design temperature differential and multiply by 24 to obtain heat loss in BTU/DD	1 - H	10	1
11. Determine monthly cooling degree days	1 - H	15	1
12. Calculate monthly BTU requirement for space cooling load	1 - H	5	1
D. Choose Collector Type			
1. Determine average operating collector fluid temperature	1 - S	60	2
2. Determine design ambient temperature and insolation	1 - S	10	1
3. Determine flat-plate and concentrating collector efficiencies for design conditions	1 - S	5	1
4. Determine cost per square foot of collector types	1 - S	20	3
5. Calculate $/BTU	1 - S	5	1
6. Choose collector type with lowest energy cost	1 - S	15	1

DESIGN STAGE	No. Persons Required Type Person	Time Required (Minutes)	Learning Difficulty
E. Calculate solar gain on unit area basis			
1. Determine collector tilt for application	1 - S	10	2
2. Determine for each month average hourly insolation for tilt and latitude	1 - S	120	3
3. Determine for each month average ambient daylight temperature	1 - S	60	1
4. Determine monthly collector efficiency from collector performance curve.	1 - S	120	3
5. Determine monthly clear day collector heat gain in BTU/Ft.^{2}-hr.	1 - S	10	2
6. Determine for each month average daily daylight collection hours	1 - S	0	1
7. Determine haze factor for locality	1 - S	0	1
8. Determine average monthly percent of sunshine	1 - S	0	1
9. Calculate unit monthly solar gain in BTU/Ft.^{2}	1 - S	10	1
F. Determine maximum available collector area			
1. Determine roof space dimensions	1 - S	30	1
2. Determine ground space dimensions	1 - S	30	1
3. Eliminate shaded spaces	1 - S	20	2
4. Determine collector physical dimensions	1 - S	5	1
5. Allow for proper spacing of collectors on flat roof	1 - S	20	1
6. Allow for proper collector tilt and azimuth	1 - S	10	2
7. Calculate maximum collector area in square feet	1 - S	10	1

DESIGN STAGE	No. Persons Required Type Person	Time Required (Minutes)	Learning Difficulty
Determine optimum collector area			
1. Multiply given collector area by monthly unit solar gain to obtain monthly solar gain in BTU	1 - S	10	1
2. Obtain monthly useful solar gain by taking the lesser of the monthly solar gain and the monthly total load.	1 - S	5	1
3. Obtain the typical annual useful solar gain in M BTU by summing the monthly totals and dividing by 10^6	1 - S	5	1
4. Determine the auxiliary fuel efficiency (decimal)	1 - S	0	1
5. Obtain auxiliary fuel saved by dividing the annual useful solar gain by the auxiliary fuel efficiency	1 - S	5	1
6. Determine cost of solar system	1 - S	90	2
7. Determine the mortgage interest rate and term	1 - S	5	1
8. Determine cost and inflation rate of auxiliary fuel	1 - S	5	3
9. Calculate life cycle value of solar system	1 - S	30	3
10. Iterate above steps with different collector areas to obtain maximum life cycle value	1 - S	180	3
(If you are using another method, please describe)			
H. Design fluid flow system			
1. Determine proper storage size and location			
2. Integrate solar and conventional systems	1 - S	120	3
3. Design system controls and operation modes	1 - S	60	3
4. Size individual system components in accordance with collector size and load requirements	1 - S	180	3
5. Prepare working drasings	1 - S	120	3
6. Prepare materials and equipment specifications	1 - S	120	3

TASK INVENTORY

INSTALLATION	No. Persons Required Type Person	Time Required (Minutes)	Learning Difficulty
I. Construct Storage System			
1. Prepare foundation	2 - X	240	2
2. Insulate foundation (Deleted by Experts)			
3. Install or construct storage container shell	2 - P	120	1
*4. Install internal container components	2 - P	180	2
5. Install temperature sensors	1 - H	60	2
*6. Make connections to system	2 - P	60	2
7. Insulate storage container	2 - X	180	2
*For Air System:			
I.4.	2 - SM	180	2
I.6.	2 - SM	120	2
J. Install collector			
1. Prepare collector mounting foundation	2 - C	20	1
2. Construct collector mountings	2 - C	30	1
3. Mount each collector	2 - S	15	1
4. Install each temperature sensor	1 - H	5	1
*5. Connect dampers, valves, safety devices as required by system design	1 - P	120	2
*6. Connect manifolds and collector pipelines	2 - P	30	2
*For Air System:			
J.5.	1 - SM	240	2
J.6.	2 - SM	90	2

INSTALLATION	No. Persons Required Type Person	Time Required (Minutes)	Learning Difficulty
K. Complete System Hookup			
* 1. Mount major solar system components: heat exchangers, air handlers, pumps, blowers, domestic hot water tanks, etc.	2 - P	600	3
* 2. Connect all solar components with pipelines as required by system design	2 - P	480	1
3. Install conventional equipment (Charged to Conventional)			
4. Make connections between solar energy components (Deleted by Experts)			
5. Install space heating and cooling ducting (Charged to Conventional)			
6. Install system controls and make connections to sensors	1 - E	240	3
7. Flush, fill, and purge (liquid system)	1 - P	240	2
8. Make electrical connections	1 - E	240	3
*For Air System:			
K.1.	2 - SM	720	3
K.2.	2 - SM	720	1
L. System checkout			
1. Leak test all pipelines	1 - P	120	2
2. Check out the system powered components	1 - S	240	3
* 3. Insulate pipelines as necessary	2 - P	480	2
4. Calibrate and test solar temperature differential controls	1 - S	120	2
5. Test system operation modes (Deleted by Experts)			
* 6. Balance flow controls as specified	1 - P	60	2
*For Air System			
L.1.	1 - SM	120	2
L.3.	2 - SM	720	2

MAINTENANCE (ROUTINE)	No. Persons Required Type Person	Time Required (Minutes)	Learning Difficulty
M. Maintenance			
1. Periodic lubrication of moving parts (pumps, blowers, etc)	1 - X	20	1
2. Filter change	1 - X	120	1
3. Clean collector glazing (Deleted by Experts)			
4. Descale heat exchangers (water side)	1 - P	48	2
5. Flush open liquid collector loops and refill with clean solution	2 - P	240	1
6. Check drain down tank for unwanted fill (liquid drain down systems) (Deleted by Experts)			
7. Check antifreeze solution strength and PH in liquid closed loop systems	1 - X	30	1
8. Check AP (water) thru collector loop (Deleted by Experts)			
9. Replace sacrificial corrosion elements and other systems components which are periodically consumed	1 - P	15	1
10. Check tracking orientation of concentrating collectors	1 - S	240	3
11. Check liquid levels in expansion and storage tanks	1 - X	15	1
12. Check normal positions of motorized valves and dampers	1 - S	60	2
13. Monitor flowrates and temperature differentials to test system operation	1 - S	60	2
*14. Check for degradation of pipeline insulation	1 - P	60	1
15. Check seals on pumps.	1 - P	5	1
*For Air Systems			
M.14.	1 - SM	60	1

Navarro College
Solar Energy Division

TASK INVENTORY

Curriculum Development
and Manpower Forecast

	No. Persons Required Type Person	Time Required (Minutes)	Learning Difficulty

Please state in one or two paragraphs a job description of what you as an employer of a solar technician would like in an employee.

Some questions to answer might be as follows:

What skills do you require?

What is the highest level of skill you desire?

APPENDIX L

TASK ANALYSIS

This appendix contains the completed task analysis produced during this project.

DESIGN STAGE

A. CALCULATE HOT WATER LOAD

1. Determine monthly average ground water temperature.
   a. Obtain ASHRAE Handbook or other reference, or contact water utility for temperature data. Record.
2. Determine design hot water temperature.
   a. Determine from building plans what types of appliances (e.g. dishwasher, clothes washer) are in use, and what water temperatures they require. (Consult local code books.)
3. Determine hot water requirement for persons.
   a. Using Uniform Solar Energy Code nomography or other reference, apply the number of persons using hot water to the graph and find total hot water consumed, or multiply number of persons by 20 gallons per day.
4. Determine hot water requirement for appliances.
   a. Repeat above procedure for appliances using nomograph, or contact manufacturer or distributor of appliance for hot water demand.
5. Determine BTU requirement of monthly hot water load.
   a. Read BTU requirement from nomograph, or multiply gallons used per day by the design temperature minus the supply water temperature and by 8.3 lbs. per gallon.

TOOLS AND EQUIPMENT

(A) Uniform Solar Energy Code or other reference

(B) Table of monthly average supply water temperatures (if available)

(c) Building plans

MATERIALS AND COMPONENTS

None

REQUIRED KNOWLEDGE

(A) Science.

(1) Familiarity with energy units.

(2) Ability to calculate temperature of a mass given the thermal energy added to the mass.

(3) Knowledge of specific heats, density of water.

(B) Mathematics.

(1) Algebra.

(2) Graph reading.

PERFORMANCE OBJECTIVE

Given a hot water demand situation in the form of building plans or existing building with hot water needs, the student will obtain all information necessary and perform all calculations to determine the daily hot water heating load in BTU per day, for any locality.

B. CALCULATE SPACE HEATING LOAD

1. Determine inside and outside design temperatures and design wind speed.
    - a. Look up design temperatures in ASHRAE Guide or other reference, record.
2. Determine U-values for structure components.
    - a. Determine ceiling, wall, floor, window, and door construction from plans or building.
    - b. Find U-values for building materials used from ASHRAE Guide or other reference. If conductances are listed, multiply conductance per inch by thickness of material in inches to get U-value. Determine U-values of air films for still air and 15 MPH wind speed. Add reciprocals of U-values for each component and find reciprocal of total.
3. Determine areas of structure components.
    - a. Measure dimensions of outside walls, ceilings, floors, windows, and walls using architectural scale of plan, or measure existing building to obtain this information, and record. Measure only the surfaces which represent the shell of the building.
    - b. Multiply length and width to obtain area.
    - c. Subtract window and door areas from gross wall areas to obtain net wall area.
    - d. Sum areas of all components which have equivalent U-values.
4. Determine infiltration of structure.
    - a. Multiply floor area obtained above by ceiling height to obtain volume of insulated space. Do for each room.

   b. Refer to ASHRAE Guide and multiply volumes above by appropriate factors depending on the number of walls with windows/doors exposed to the outside. (Alternately, calculate infiltration using ASHRAE "Crack" method.) Do for each room.

5. Calculate total heat loss under design conditions in BTU/hr.
   a. Subtract outdoor design temperature from indoor design temperature 70°F found in step one.
   b. Multiply the area times the U-value for each building component by the design temperature differential found in step (a), and record in tabular form. Sum these values to obtain the conduction heat-loss. For infiltration, multiply the infiltration rate values from 4.b. by .018 and be the design temperature differential and add them to the conduction heat loss to obtain the design heat loss.
6. Divide design heat loss by design temperature differential and multiply by 24 to obtain heat loss in BTU/DD.
7. Determine monthly heating degree days.
   a. Find the heating degree-days for the locality under consideration in the ASHRAE Guide or from the National Climatic Center, for each month. Record.
8. Determine degree day correction factor for outside design temperature.
   a. Refer to the ASHRAE Guide.
9. Calculate monthly BTU requirement for space heating load.
   a. Multiply the heat loss in BTU per degree-day by the number of degree-days in each month. Record the monthly heating load in BTU x 10^6 or therms (BTU x 10^5).

TOOLS AND EQUIPMENT

(A) ASHRAE Handbooks, Fundamentals and Systems, or other reference.

(B) Tape measure and/or architectural scale.

(C) Building plans or building

(D) Engineering note pad

(E) Calculator

MATERIALS AND COMPONENTS

None

REQUIRED KNOWLEDGE

(A) Science

- (1) Knowledge of energy units
- (2) Simple physics of heat transfer (conduction, convection, radiation).

(B) Mathematics

- (1) Ability to convert units
- (2) Algebra.
- (3) Trigonometry.

PERFORMANCE OBJECTIVE

Given a building constructed of a variety of materials, the student will determine what references and information are required, will obtain them, and will calculate the design heat loss monthly heating load of the structure for any locale.

C. CALCULATE SPACE COOLING LOAD

1. Determine inside and outside design temperatures, latitude, and daily temperature range.

   a. Using an appropriate climatic reference (ASHRAE Handbook of Fundamentals or equivalent) consult table to obtain 97½% outdoor summer design wet bulb and drybulb temperatures, and daily temperature range for the particular location.

   b. Assume an indoor summer design dry bulb temperature of 79°F and wet bulb temperature of 62°F if indoor relative humidity is to be maintained at 50%. For other desired humidity levels, determine indoor wet bulb temperature from psychometic charts corresponding to desired humidity level and interior dry bulb temperature.

   c. From a map or other geographic reference obtain the latitude of the location.

2. Determine equivalent temperature differences.

   a. Using ASHRAE Handbook of Fundamentals, determine equivalent temperature for each structural component with respect to surface orientation, outdoor design temperature (db) and daily temperature range.

3. Determine U-values for structural components.

   a. Method 1 - If U-values for winter conditions have been previously calculated, adjust those values for changes in wind velocity and direction of heat transmission according to charts and tables in ASHRAE Handbook of Fundamentals and other comparable references.

b. Method 2 - If U-values for winter conditions have not been calculated, determine thicknesses and compositions of each portion of the structure (walls, roof, etc.). Then consult an appropriate reference to determine resistance values, conductance values, or conductivity values of each structure. Perform the mathematics to convert these values to "resistances" as required. Add the resistances of each component of the structure, making adjustments for framing per Handbook of Fundamentals as required add the interior and exterior air resistance values corresponding to the direction of heat transmission, (horizontal, vertical; up or down, etc.) and wind velocity. Take the reciprocal of the sum of the resistances to obtain the U-value for the structure.

4. Determine areas of structure components.

    a. Procedure is identical to that specified in section B.3.a. for space heating load.

5. Determine window shading.

a. Horizontal overhangs

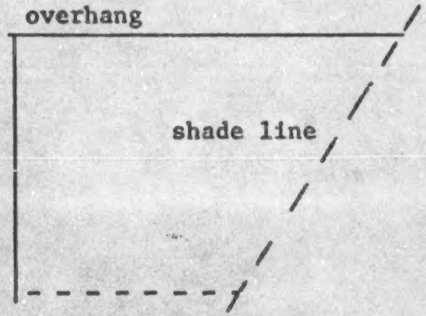
(1) Make a table of window orientations (cardinal pts.)

N	NE	E	SE	S	SW	W	NW	5 a (1)
SHADE LINE FACTOR								5 a (2)
WINDOW AREAS - SHADED								5 a (5)
UNSHADED								5 a (6)
S.H.G.F.								

(2) Consult Handbook of Fundamentals and determine shade line factors for each orientation and enter into the table the corresponding orientation.

(3) Determine the length of the overhang from building plans for each orientation.

(4) Multiply result in 5 a (3) by shade line factor for each appropriate orientation to give the position of the time-averaged shade line.



(5) Determine the area for each window and orientation that is below the shade line and the area that is above the shade line. Add the results for each window of the same orientation to give a total window area that is shaded and a total window area that is unshaded. Enter the results into the table.

(6) From Handbook of Fundamentals determine a solar heat gain factor for each window orientation according to type of window construction and interior shading devices (drapes, venetial blinds, etc.).

(7) Calculate solar heat gain by multiplying solar heat gain factor for each window orientation by the unshaded window area for the corresponding orientation. Add to that the solar heat gain through the shaded areas which is calculated by multiplying the solar heat gain factor for North orientation by the sum of the shaded window areas for all orientations.

NOTE: Tasks 5.a (1) through (7) represent the accepted ASHRAE procedure for solar heat gain through fenestrations for residential structures.

8. Calculate internal heat gains.

a. Sensible heat gains.

(1) Gain due to occupants multiply # of occupants by 250 to give sensible load in BTU/hr. for occupancy.

(2) Gain due to appliances. Determine from building plans the types of appliances that will contribute to the internal heat gein of the structure (kitchen appliances epsecially). Consult Handbook of Fundamentals on other source to determine the heat gain for each appliance.

(3) Determine ventilation requirements and/or infiltration.

(a) In most cases infiltration is adequate for ventilation requirements. Assume ½ change in volume of air per hour. Calculate total volume of structure. Determine sensible gain by multiplying infiltration rate (above) by .018 x (ΔT_{db}) to get infiltration gain in BTU/hr.

(b) If infiltration is not sufficient for ventilation needs (refer to Handbook of Fundamentals of other reference to make this determination within the constraints of the particular problem), determine ventilation rate in CFM. Sensible gain in BTU/hr. = (1.1) (CFM) x Δt_{db}

b. Latent heat gains. For residential method, calculate total latent gain from total sensible gain for the structure (step 9).

9. Calculate total heat gains under design conditions.

a. Sum individual sensible gains for each structure. Multiply sum by .3 to give latent gain for residential structures. (Check ASHRAE Handbook of Fundamentals to determine whether this method of calculating latent gain applies. If not, calculate latent gains independently.

b. Total heat gain is sum of latent and sensible gains.

10. Multiply total heat gain BTU/hr. by Δt_{db} design and 24 to obtain gain in BTU/DD.

11. Calculate monthly cooling degree days.

a. Using publication 81 of N.O.A.A. (Nat. Oceanic and Atmospheric Administration) MONTHLY NORMALS OF TEMPERATURE, PRECIPATION

(3) Determine ventilation requirements and/or infiltration.

(a) In most cases infiltration is adequate for ventilation requirements. Assume ½ change in volume of air per hour. Calculate total volume of structure. Determine sensible gain by multiplying infiltration rate (above) by .018 x (ΔT_{db}) to get infiltration gain in BTU/hr.

(b) If infiltration is not sufficient for ventilation needs (refer to Handbook of Fundamentals of other reference to make this determination within the constraints of the particular problem), determine ventilation rate in CFM. Sensible gain in BTU/hr. = (1.1) (CFM) x Δt_{db}

b. Latent heat gains. For residential method, calculate total latent gain from total sensible gain for the structure (step 9).

9. Calculate total heat gains under design conditions.

a. Sum individual sensible gains for each structure. Multiply sum by .3 to give latent gain for residential structures. (Check ASHRAE Handbook of Fundamentals to determine whether this method of calculating latent gain applies. If not, calculate latent gains independently.

b. Total heat gain is sum of latent and sensible gains.

10. Multiply total heat gain BTU/hr. by Δt_{db} design and 24 to obtain gain in BTU/DD.

11. Calculate monthly cooling degree days.

a. Using publication 81 of N.O.A.A. (Nat. Oceanic and Atmospheric Administration) MONTHLY NORMALS OF TEMPERATURE, PRECIPATION

AND HEATING AND COOLING DEGREE DAYS, determine monthly cooling degree days for the particular location.

12. Calculate monthly BTU requirement for space cooling load by multiplying results of C.10, i.e. (BTU/DD), by monthly cooling degree days to give monthly space cooling load.

    a. Determining size of components; From total cooling load, total sensible load and total latent load at interior and exterior design conditions (w.b. & d.b. temperatures) consult manufacturers data on cooling units to determine required capacity of unit

TOOLS AND EQUIPMENT

(A) Calculator with scientific functions.

(B) Reference materials: HVAC manual or ASHRAE publications; Architectural Graphics Standards or equivalent to interpret architectural drawings; degree-day data and temperature data - publications available from N.O.A.A. et.al.

(C) Architects Rule.

(D) Data Pads.

REQUIRED KNOWLEDGE

(A) Science
    (1) Fluid mechanics
    (2) Thermodynamics
    (3) Library research skills

(B) Mathematics
    (1) Algebra
    (2) Trigonometry
    (3) Calculator skills

PERFORMANCE OBJECTIVE

Given a set of architectural drawings (floor plans, elevations, structural and mechanical details), for a residence which shows site orientation, necessary reference materials including ASHRAE Handbook of Fundamentals, summer design temperature and cooling degree data, architects rule and scientific calculator, the student will perform all the necessary measurements and calculations to determine the sensible and latent cooling load of the building.

D. CHOOSE COLLECTOR TYPE

1. Determine average operating collector fluid temperature.
    - a. Obtain manufacturers specifications on collector performance.
    - b. From collector manufacturers' specs obtain average operating collector fluid temperature that corresponds to design demands for temperature out of collector.
    - c. Enter this temperature on worksheet.
2. Determine design ambient temperature and insolation.
    - a. Obtain ASHRAE Handbook of Fundamentals or other source of meteorological and insolation data.
    - b. Look up for design month the ambient temperature and insolation values.
    - c. Enter values on worksheet.
3. Determine flat-plate and concentrating collector efficiencies for design conditions.
    - a. Obtain manufacturer's specifications for collector performance
    - b. Read design conditions from worksheet.
    - c. Enter performance graph on bottom axis at point defined by

$$\frac{T_{in} - T_{ambient}}{\text{Insolation}}$$

and go up to curve then horizontally to vertical axis and read collector efficiency.

    - d. Enter results on worksheet.

4. Determine cost per square foot of collector types.

   a. Obtain collector cost from manufacturers or sales outlet.

   b. Obtain effective solar absorber area from manufacturers literature.

   c. Divide cost of total collector by effective solar absorber area to get $\$/ft^2$ collector.

   d. Enter results in worksheet.

5. Calculate $/BTU.

   a. From D.3 above enter collector efficiency and design insolation in equation below

$$\frac{\$}{\text{BTU}} = \frac{\text{Cost/Effective Area}}{\text{Insolation x Efficiency}}$$

   b. From D.4 above enter collector cost per square foot of absorber area in equation above.

   c. Solve equation for $\frac{\$}{\text{BTU}}$

   d. Enter results in worksheet.

6. Choose collector type with lowest energy cost.

   a. From list of $/BTU in D.5 above choose collector with lowest $/BTU value.

TOOLS AND EQUIPMENT

(A) Manufacturers performance specifications (graph)

(B) Pen or pencils

(C) Paper (worksheet)

(D) ASHRAE Handbook or other source of local meteorological and insolation data.

(E) Pocket calculator.

(F) Manufacturers price sheets.

MATERIALS AND COMPONENTS

None

REQUIRED KNOWLEDGE

(A) Science

- (1) Basic heat transfer theory
- (2) Temperature effect on properties of materials
- (3) Basic sun-earth relationship (astronomy)
- (4) Meaning of temperature, effective area, efficiency, insolation.

(B) Mathematics

- (1) Arithmetic.
- (2) Algebra.
- (3) Graph reading.
- (4) Data chart reading.
- (5) Concepts of area, price, lower versus higher value.

PERFORMANCE OBJECTIVE

Given manufacturers' specifications and local climatological data, the student will make the proper calculations and choose the type of collector best suited to the needs of the application.

E. CALCULATE SOLAR GAIN ON UNIT AREA BASIS

1. Determine collector tilt for application.
   - a. Find local latitude from maps or atlas.
   - b. Determine solar application from client or blueprints and specifications as to whether it is space heating only, water heating only, or both space heating plus water heating.
   - c. If space heating only, a thumb rule for collector tilt plus 15 degrees will be appropriate to make use of the winter sun's position in the sky.
   - d. If water heating only, a thumb rule for collector tilt equal to the latitude will allow year round use of collector.
   - e. If combination of space heating and water heating is required, then the tilt is the same as that of space heating only.
   - f. Enter results in worksheet.
2. Determine for each month average hourly insolation for tilt and latitude.
   - a. Obtain ASHRAE insolation tables.
   - b. Obtain local latitude and tilt from E.1. above.
   - c. Enter ASHRAE tables for local latitude or closest latitude for which there is a table in the month of January.
   - d. Read across to tilt closest to that determined in E.1. above.
   - e. Enter in worksheet the hourly values for insolation.
3. Determine for each month average ambient daylight temperature.
   - a. Obtain ASHRAE Handbook or other source of temperature data.
   - b. Enter table for geographic location and list average daily daylight temperature.

4. Determine monthly collector efficiency from collector performance curve.
    a. Obtain manufacturers efficiency curves.
    b. Using the following equation

$$x = \frac{T_{in} - T_{ambient}}{I_{design}}$$

determine "x" value using design insolation, collector design inlet temperature, and ambient temperature.

    c. Enter manufacturer's efficiency curves on horizontal axis at "x", move vertically to curve, then horizontally to vertical axis and read collector efficiency.
    d. Follow above procedure for each month of the year.
5. Determine monthly clear day collector heat gain in BTU/Ft.^{2} -hr.
    a. From E.2. above sum all hourly insolation values greater than

$$\frac{125\ \text{BTU/hr}}{\text{ft.}^2}$$

    b. Multiply daily clear day insolation (above) by collector efficiency from E.4. above.
6. Determine for each month average daily daylight collection hours.
    a. Obtain ASHRAE Handbook.
    b. Enter tables for closest latitudes and read number of daily daylight hours.
7. Determine haze factor for locality.
    a. Obtain local meteorological data from colleges, airports, Federal Government, or State Government, etc.
    b. Look up haze factor for locality.

8. Determine average monthly percent of sunshine.

    a. Subtract haze factor % from 100% to obtain % sunshine.

9. Calculate unit monthly solar gain in BTU/Ft.^{2}, using information obtained in above steps.

TOOLS AND EQUIPMENT

(A) Maps, Atlas, etc.

(B) Blueprints or specifications

(C) ASHRAE Handbook or other data source

(D) Pocket calculator

(E) Source of local meteorological data

(F) Pen or pencils

(G) Paper (worksheet)

MATERIALS AND COMPONENTS

None

REQUIRED KNOWLEDGE

(A) Science

- (1) Geography
- (2) Sun/earth relationships
- (3) Astronomy
- (4) Meaning of temperature, efficiency, insolation
- (5) Basic heat transfer theory
- (6) Percentages

PERFORMANCE OBJECTIVE

Given the local climatological data and the manufacturer's specifications, the student will calculate the solar gain on a unit area basis.

F. DETERMINE MAXIMUM AVAILABLE COLLECTOR AREA

1. Determine roof space dimensions.
    a. Obtain blueprints or drawings (to scale) of building.
    b. Using engineers or architects scale or actual on site measurement with tape measure, measure all areas of roof that give good southern exposure.
    c. Enter this area on worksheet.
2. Determine ground space dimensions.
    a. Obtain tape measure.
    b. At the site, measure length and width of ground space available for storage tank or collector placement.
    c. Enter area on worksheet.
3. Determine shaded spaces.
    a. Obtain sun angle locator box.
    b. Positioning yourself so that you are eye level with the bottom of the proposed collector array, use sun angle locator box, positioned parallel with long axis of roof, to find time of year and position of shade devices.
    c. Mark areas that will be shaded on roof/ground diagram.
    d. Measure these areas.
4. Determine collector physical dimensions.
    a. Look up dimensions on manufacturer's specification sheet.
5. Allow for proper spacing of collectors on flat roof.
    a. Obtain ASHRAE Handbook.
    b. Look up solar altitude at 10:00 a.m. on December 21.
    c. On separate sheet of paper draw to scale, side view of collector array with proper tilt and collector height.

    d. Using protractor, find the point on the north side of collectors where a line drawn at an angle equal to the altitude would just touch the upper edge of the collector.

    e. Measure the distance from the back of the collector array to this point with architects or engineers scale.

6. Allow for proper collector tilt and azimuth.

7. Calculate maximum possible collector area in square feet.

    a. Subtract from gross area those areas that were not usable.

TOOLS AND EQUIPMENT

(A) *ASHRAE Handbook*.

(B) Protractor.

(C) Scales.

(D) Tape measure.

(E) Architect's or Engineer's scale.

(F) Sun angle locator.

MATERIALS AND COMPONENTS

None.

REQUIRED KNOWLEDGE

(A) Science.

    (1) Sun/earth relationships.

    (2) Astronomy.

(B) Mathematics.

    (1) Measuring skills.

    (2) Algebra.

    (3) Arithmetic.

    (4) Trigonometry.

PERFORMANCE OBJECTIVE

Given blueprints or existing house and plot dimensions, the student will calculate the usable area for collector placement.

G. DETERMINE OPTIMUM COLLECTOR AREA

1. Multiply given collector area by monthly unit solar gain to obtain monthly solar gain in BTU.
   a. Obtain collector area from F.7.above.
   b. Obtain monthly unit solar gain from E.9.
   c. Multiply these numbers together.
2. Obtain monthly useful solar gain by taking the lesser of the monthly solar gain and the monthly total load.
   a. By looking at a column of monthly useful solar gain and a column of monthly total load enter the lesser of the two numbers for each month in a third column.
3. Obtain the typical annual useful solar gain in M BTU by summing the monthly totals and dividing by 10^6.
   a. Add all the numbers in the third column in G.2. above.
   b. Divide this number by 10^6 to obtain M BTU.
4. Determine auxiliary fuel efficiency.
   a. Obtain written data on fuel efficiency if possible.
5. Obtain auxiliary fuel efficiency.
   a. Multiply value in G.4. above by annual useful solar gain.
6. Determine cost of solar system.
   a. Obtain collector cost information from manufacturers.
   b. Multiply collector cost by the number of collectors to get solar collector costs.
7. Determine the mortage interest rate and term.
   a. Obtain list of mortage rates from local building institution.
   b. From this list determine mortgage rate based on system cost and lifetime.

8. Determine cost and inflation rate of auxiliary fuel.
    a. Obtain list or table of local utility rates.
    b. From this table determine rate which applies to the specific application (residential, commercial, etc.)
    c. Obtain from local Public Utilities Commission estimates for fuel inflation rates.
    d. From this information determine which rate applied.
9. Calculate life cycle value of solar system.
    a. Enter data collected above in following formula:

$ = Capital cost of solar system

$$\$ = \left[\begin{array}{l}\text{Capital cost of solar system}\\ \text{including tax incentives or}\\ \text{other factors as reflected}\\ \text{in \$/BTU}\end{array}\right] + \left[\begin{array}{l}\text{present value of fuel}\\ \text{cost over lifetime of}\\ \text{system}\end{array}\right] + \left[\begin{array}{l}\text{present value of stream of}\\ \text{maintenance costs over life-}\\ \text{time of system}\end{array}\right]$$

10. Iterate above steps with different collector areas to obtain maximum life cycle value.

TOOLS AND EQUIPMENT

(A) Pocket calculator.
(B) Mortgage rate table.
(C) Utility rate schedules.

MATERIALS AND COMPONENTS

None

REQUIRED KNOWLEDGE

(A) Science

None

(B) Mathematics

(1) Arithmetic

(2) Albegra

(3) Percentages

(4) Table interpretation

PERFORMANCE OBJECTIVE

Given mortgage rates, fuel rates, and various collector areas, the student will determine the optimum collector area for the application.

H. DESIGN FLUID FLOW SYSTEM

1. Determine proper storage size and location.
    - a. Locate outside tank in area protected from the elements. Locate inside tank in mech room insulated from conditioned space if used in summer.
    - b. Determine application BTU/Hr design load requirements from A, B, & C as applicable.
    - c. Determine hours of storage required for application, typically 24 hours for heating and hot water and three to four hours for cooling.
    - d. Determine BTU storage requirement by multiplying hours of storage by BTU/Hr requirement.
    - e. Determine design maximum storage temperature and minimum useful storage temperature.
    - f. Divide BTU by the difference between maximum and minimum temperatures and divide the result by 8.33 to obtain storage size in gallons.

$$\text{GAL} = \frac{\text{BTU}}{8.33 \times \Delta T}$$

2. Integrate solar and conventional systems.
    - a. For air systems, determine proper location of solar duct tie-ins. For liquid systems, determine location of water coil in conventional ductwork.
3. Design system controls and operation modes.
    - a. Use two stage thermostat to bring on solar first and conventional equipment second.
    - b. Use temperature sensors and relays to prevent the circulation of the solar working fluid to the load when the fluid is not hot enough to help meet the load.

   c. Use a differential control and sensors to ensure that the solar collectors recharge storage and do not degrade it.
   d. Use a motorized valve or check valve to ensure that storage is not degraded by thermal siphoning backflow.
   e. Include relief valves, air vents, vacuum breakers, and tempering valves as necessary.

4. Size individual system components in accordance with collector size and load requirements.
   a. Determine CFM and GPM for conventional equipment and solar collectors.
   b. For liquid systems, choose water coil that meets BTU/hr load requirements at design minimum useful solar supply water temperature.
   c. For air systems, choose air to water exchanger to meet domestic hot water requirements at collector design CFM and outlet temperatures.
   d. For liquid systems requiring a water to water heat exchanger between the collector and storage, determine collector fluid specific heat, GPM, and outlet temperature; and determine tank minimum flow over the exchanger surface and design inlet temperature. Refer to manufacturer for exchanger size.
   e. Design duct and pipe sizes for required CFM and GPM not exceeding friction loss and velocity limits specified in ASHRAE handbook.
   f. Choose the smallest pump and fan models that exceed or equal design CFM and GPM at required static pressure and head.

5. Prepare working drawings.
   a. Determine schematic representation of system components: pipelines, valves, dampers, fans, pumps, storage, collectors, conventional equipment, etc.
   b. Draw wiring diagrams linking thermostats, relays, temperature sensors, and mechanical system components.

c. Use building plans to determine physical location of components.

6. Prepare materials and equipment specifications.

   a. Determine lengths of various duct and pipe sizes needed.

   b. Determine number and sizes of elbows, tees, gate valves, manual dampers, registers, and other small passive fittings for pipeline connections.

   c. Determine number and sizes of motorized valves and dampers, pumps, fans, differential controls, thermostats, relays, relief valves, vacuum breakers, air vents, expansion and compression tanks, aquastats, and other small active system components.

   d. Determine number and model of collectors, furnaces, air conditioning units, storage tanks, or other large system equipment.

TOOLS AND EQUIPMENT

(A) ASHRAE Handbook or other HVAC manual

(B) Handbook of Physics and Chemistry or other source of physical property.

(C) Calculator

(D) Manufacturers' component specifications.

(E) Unit Conversion Tables.

(F) Note pad.

(G) Building plans.

(H) Architects Rule.

(I) Drafting equipment.

MATERIALS AND COMPONENTS

None

REQUIRED KNOWLEDGE

- (A) Science.
  - (1) Basic heat transfer theory.
    - (a) Meaning of temperature.
    - (b) Specific heat.
    - (c) Heat exchanger equations.
  - (2) Fluid flow theory.
    - (a) Pipe sizing.
    - (b) Duct sizing.
  - (3) Understanding of pump and fan characteristics.
  - (4) Low voltage control theory
    - (a) General Principles
    - (b) Component characteristics, e.g. thermostats, relays, temperature sensors.
  - (5) Basic Electric Circuit theory.
- (B) Mathematics.
  - (1) Graph and table reading.
  - (2) Arithmetic.
  - (3) Algebra.
  - (4) Understanding of units conversion.

PERFORMANCE OBJECTIVE

Given the building plans, thermal loads, and solar collector size, the student will design an energy collection and delivery system that provides adequate solar storage, efficient heat transfer, safe operation, and adequate auxiliary equipment to meet design loads.

I. CONSTRUCT STORAGE SYSTEM.

1. Prepare foundation.

    a. Locate site for storage container. If container is to be above grade, clear and level ground. If container is to be buried, excavate hole for storage tank, leaving enough room to inspect tank for leaks and for insulation.

    b. For above grade tanks, determine size and method of mounting of tank and mark off approximate dimensions, or refer to plans for foundation dimensions.

    c. Excavate footing of foundation (if required by plans or local codes).

    d. Set stakes at corners of foundation and set up strings to mark of foundation, check square of foundation by measuring diagonals Adjust string lines so that the foundation is of the proper dimensions and squared.

    e. Cut form boards to coincide with string line dimensions and firmly nail corners. Set stakes around perimeter of forms. Raise form to desired level at one corner and nail to stake. Nail remainder of stakes to form, checking with level to insure the entire form is at the same level as the first corner nailed. Drive stakes at an angle (sway brace) and with inside of form lined up with string, nail stake to form. Remove string.

    f. Lay down wire reinforcing mesh if required.

    g. Pour concrete into form, spreading with flat shovel or concrete rake. Remove excess concrete by sliding 2 x 4 "rod" along tops of forms. tamp concrete with tamping device such as "jitterbug". Level and fill in holes with float. Set foundation bolts (if required to secure wall plates or tank cradle). Allow concrete to set slightly and trowel with hand trowel and/or "fresno". Hand trowel to achieve finished surface.

h. After concrete has set, strip forms and remove stakes.

2. Deleted by experts.

3. Install or construct storage container shell.

   a. (NOTE: It is assumed the technician will not construct the storage container, but will install a prefabricated system. There are a diversity of ways to construct storage systems for air and water systems which would require extremely lengthy discussions.) Unload storage container from delivery vehicle. If fork-lift or crane is required, insure that the tank or storage device is not subject to damage at the lifting points.

   b. Using manpower, forklift, or crane, set storage device on foundation or other prepared mounting, or in excavated hole. Bolt or otherwise secure.

4. Deleted by experts.

5. Deleted by experts.

6. Make connections to system.

   a. Insert threaded nipples into tank fittings (if required, applying pipe joint compound to male threads. Thread dielectric unions onto nipples (if required) and tighten with pipe wrench. (Disregard if air system.)

   b. Assemble fittings of proper size and type required to make connection between tank and plumbing stub-outs, (or duct fittings). Cut pipe or duct to appropriate lengths.

   c. Assemble fittings and pipe and double-check pipe lengths. Apply flux to cleaned pipe and fittings, re-assemble, and solder joints. (Remove rubber or plastic parts of fittings before soldering to prevent damage.) For air systems, connect duct to collars on storage tank and tape seams with duct tape.

7. Insulate storage container.

   a. Wrap tank with fiberglass, or spray tank with foaming equipment, or laminate board insulation to tank with contact cement.

   b. If tank is to be exposed to moisture or ultraviolet radiation, wrap fiberglass insulation with plastic material and secure by banding or heat sealing, or paint foam insulation with latex sealant.

TOOLS AND EQUIPMENT

(A) Shovel, pick, backhoe, trencher.

(B) Wooden or metal stakes.

(C) Tape measure.

(D) Nylon string.

(E) Circular saw.

(F) Level, hammer, nail puller, square.

(G) Wire cutters.

(H) Concrete rake, "jitterbug", "fresno".

(I) Hand float, bull float, hand trowel.

(J) Wrench set.

(K) Fort lift, crane.

(L) Screw driver, crescent wrench, pipe wrench.

(M) Propane torch, striker.

(N) Tubing cutter.

(O) Wire strippers.

(P) Paint brush.

(Q) Banding tool.

(R) Foam gun.

(S) Utility knife.

MATERIALS AND COMPONENTS

(A) Storage container.

(B) Nails, bolts, screws.

(C) Wire mesh.

(D) Concrete.

(E) 2 x 4 lumber.

(F) Epoxy or thermal glue.

(G) Clamps.

(H) Pipe joint compound.

(I) Thermostat wire.

(J) Wire nuts.

(K) Conduit.

(L) Pipe and fittings.

(M) Flux, emergy cloth.

(N) Duct tape.

(O) Insulating material(foam, board, or batt).

(P) Contact cement.

(Q) Plastic film.

(R) Latex sealant.

(S) Aspirator.

REQUIRED KNOWLEDGE

(A) Science

None

(B) Mathematics

(1) Arithmetic

PERFORMANCE OBJECTIVE

Given a storage tank, or rock storage bin, or other solar thermal storage device, the student will make the necessary preparations for the installation of the storage device. He will also recognize the method of making connections to the storage device with the help of system schematics, and will make these connections, including plumbing, ducting, and control sensors. He will be familiar with the different types of insulation, and with the proper equipment, will apply the insulation in a professional manner.

J. INSTALL COLLECTOR

1. Prepare collector mounting foundation.
    a. Mark points on roof where collector mounts are to be placed.
    b. Clean area of all loose roofing materials.
    c. Drill holes into roofing joints through roof.
    d. Lay in flashing material or roofing mastic/tar or both according to plans.
    e. Put collector mounting foundation in place and flash around it.
2. Construct collector mountings.
    a. Obtain blueprints or plans of collector mountings.
    b. Obtain material needed per plan (assess here wood mountings).
    c. Attach vertical supports to foundation.
    d. Attach angled supports (angle = tilt) to foundation.
    e. Attach angled supports to vertical supports.
    f. Attach all vertical supports together with wood members (2 x 4)
    g. Paint mountings.
3. Mount each collector.
    a. Obtain collectors from manufacturer.
    b. Raise collector onto roof.
    c. Place collector on mounting being careful not to damage copper heads or mountings.
    d. Fasten collector to mounting per blueprints.
4. Install each temperature sensor.
    a. Obtain thermistor or other sensing device per plan.
    b. If well type temperature sensor is used, insert probe in temperature well, being careful not to damage probe.

c. If strap-on type probe is used, attach probe to collector pipe storage tank with tape or mechanical clamps insuring that sensing points are fimly touching area to be measured.

*5. Connect dampers, valves, safety devices as required by system design.

a. Obtain necessary materials (i.e. air vents, relief valves, etc.)

b. Determine placement of air vents at all high points in system or per blueprints.

c. Determine relief valve placement at hottest point in system.

d. Using 3/4" copper FPT adapter, install air vents and relief valves using teflon tape on threads.

6. Connect manifolds and collector pipelines.

a. Obtain blueprint and material, i.e. pipe. elbows, couplings, etc.

b. Measure distances between collector.

c. Cut pipe length accordingly.

d. Clean and flux pipe (copper).

e. Connect pipe between collector.

f. Solder pipe fittings.

g. Insure that pipe lines are sloped such that air vents are at high points.

*Note: J.5. and J.6 should be done at the same time at least for hydronic systems.

TOOLS AND EQUIPMENT

(A) Blueprints or plans.

(B) Wire brush.

(C) Electric drill and bits

(D) Extension cords.

(E) Tape measure.

(F) Hammer, framing square.

(G) Paint brushes.

(H) Chair hoist or other lifting apparatus.

(I) Screw driver, pipe wrench.

(J) Knife, level, pipe cutter.

(K) Propane torch.

(L) Flux brush.

MATERIALS AND COMPONENTS

(A) Flashing material

(B) Redwood 4 x 4's.

(C) Steel angle.

(D) Brushes.

(E) Wood fasteners.

(F) Nails.

(G) Lumber (2 x 4), (2 x 6).

(H) Paint and primer.

(I) Thermistors or thermocouples.

(J) Tape.

(K) Solar collectors.

(L) Collector hold down fasteners.

(M) Air vents, relief valves.

(N) Pipe, fittings and adapters.

(O) Teflon tape.

(P) Solder, flux.

REQUIRED KNOWLEDGE

(A) Science

- (1) Building construction.
- (2) Properties of metal and wood.
- (3) Wood preservation.
- (4) Meteorology.
- (5) Mechanical advantage.
- (6) Basic heat transfer theory.
- (7) Basic electrical theory.
- (8) Basic fluid flow theory.
- (9) Corrosion processes.
- (10) Basic plumbing theory.

(B) Mathematics.

- (1) Arithmetic.
- (2) Basic measuring skills.
- (3) Trigonometry.

PERFORMANCE OBJECTIVE

Given the proper tools and components, the student will install a collector array in such a way that is meets appropriate codes and standards and is done in a workmanlike manner.

K. COMPLETE SYSTEM HOOKUP

1. Mount major solar system components: heat exchangers, air handlers, pumps, blowers, domestic hot water tanks, etc.
    a. Select location for air handler.
    b. Construct plenum of wood or sheet metal for return air to match dimensions of air handler, or mount return air box (sheet metal) and attach collar. Install return air grill. Insulate plenum.
    c. Place or suspend air handler. If suspended, hang with sheet metal straps. If installed vertically, fasten down with screws over return air plenum.
    d. Install pumps. If 1/12 H.P. or under, support with plumbing, insuring plumbing is well anchored. If greater than 1/12 H.P., nail mounting block to suitable wall, etc. and fasten pump to block with lag or machine screws. Use dielectric unions where cast iron pump is connected to copper lines.
    e. Set domestic water heater tanks in place. If tank is placed on upper story, install sheet metal drip pan underneath.
2. Connect all solar components with pipelines as required by system design.
    a. Connect return air box (if used) to return air plenum with suitable duct material. Also connect supply air plenum to supply boxes (boots), using Y's and appropriate sized duct. Tape all joints and insulate if not using pre-insulated duct. Set supply air registers.
3. Install conventional equipment.
    a. (Breakdown of tasks omitted since task is for non-solar equipment.)

4. Deleted by experts.

5. Install space heating and cooling ducting. (See 2.a.)

6. Install system controls and make connections to sensors.

    a. Fasten controls to wall or other location.

    b. Connect thermostat wire from sensors to terminal strip or to control leads with wire nuts (previously described).

    c. Connect all relays, thermostats, in manner described above.

7. Flush, fill, and purge (liquid system).

    a. Fill system in manner prescribed by plans.

    b. Check all pumps to insure that they are circulating water and not cavitating as a result of air in the water lines. Bleed off air through air bleeds or by loosening fittings.

    c. Turn pumps on and off several times to insure system is free of air and that pumps are not cavitating.

8. Make electrical connections.

    a. Attach conduit to control box and to junction box (if required).

    b. Feed wire (of proper gauge) through conduit.

    c. Connect leads in junction box (insure power is off) using wire nuts. Also connect leads at control to terminal strip or to appropriate leads.

    d. Secure covers to junction box and control box.

    TOOLS AND EQUIPMENT

    (A) Complete tool kit including wrenches, screw drivers, nut drivers, wire strippers, sheet metal shears, and pliars.

    (B) Propane torch and soldering apparatus, tubing cutters.

(C) VOM.

(D) Conduit tubing bender.

(E) Hack saw and high speed drill with bits.

MATERIALS AND COMPONENTS

(A) Heat exchangers, air handlers, pumps, blowers, domestic hot water tanks, etc.

(B) Copper pipe and fittings.

(C) Duct and duct fittings.

(D) Thermostat and high voltage wire, wire nuts.

(E) Hose

REQUIRED KNOWLEDGE

(A) Science.

  (1) Physics.

  (2) Electricity.

(B) Math.

  (1) Measuring skills.

  (2) Simple algebra.

PERFORMANCE OBJECTIVE

Given the system components to be installed, a system schematic and wiring diagrams, the student will, using the proper tools, mount all system components, and make plumbing, electrical, and other connections to the components. He will fill the system and insure that the system is entirely ready to be placed into operation. During the wiring phase, he will safeguard himself and others against electrical shock and insure his connections will not create a fire hazard, or cause damage to system components.

L. SYSTEM CHECKOUT

1. Leak test all pipelines.
   a. Inspect all joints in piping for moisture.
   b. Drain and solder any faulty joints.
2. Check out the system powered components.
   a. Insure power is delivered to system components.
   b. Place system in all possible operating modes by manually switching control and/or shorting sensor wires.
   c. Check operation of pumps, automatic valves and other components in all modes to insure their operation complies with the intended mode of operation.
   d. Return control overrides to normal position.
3. Insulate pipelines as necessary.
   a. Apply pipe insulation according to method appropriate to insulation being used (hot water pipe only).
   b. Cover, tape, or seal any insulation exposed to weather.
4. Calibrate and test solar temperature differential controls.
   a. If control system is factory calibrated, inspect operation of system under various temperature and insolation conditions. Insure that system is operating in proper modes.
   b. If control is not factory calibrated, test by immersing sensors in water at various temperatures. Monitor water temperature with thermometer and check differential on and off temperatures and high or low limit functions. Use VOM to check position of relays.

5. Test system operation modes.
   a. Observe system operation under different temperature and insolation conditions. Use overrides where necessary to simulate operation conditions.
   b. Check position of all valves and operation of pumps and relays in all modes.
6. Balance flow controls as specified.
   a. Using flow meters or collector temperature monitors, adjust flow controls to achieve balanced flow rate or uniform temperature at all collectors.
   b. Flow control valves should be wide open and then gradually closed to achieve proper balance and flow rate.

TOOLS AND EQUIPMENT

- (A) Utility knife.
- (B) Plumbing equipment (torch, solder, pipe wrench, etc.)
- (C) Complete tool kit.
- (D) Flow meters.
- (E) Thermometers (electronic) and VOM.

MATERIALS AND COMPONENTS

- (A) Pipe insulation, jacketing, sealant.
- (B) Test leads.

REQUIRED KNOWLEDGE

- (A) Science:
  - (1) Basic electrical circuitry.
  - (2) Basic fluid mechanics.
  - (3) Basic heat transfer theory.
  - (4) Basic control theory.

(B) Mathematics

    (1) Arithmetic

    (2) Algebra

    (3) Basic measuring skills

PERFORMANCE OBJECTIVE

Given test equipment, system schematics, and other tools, the student will determine that the system is operating as intended and will correct or make adjustments on the system such that it does operate correctly, or determines what components are operating in a faulty manner and require replacement or repair by specialized technicians. He will also take responsibility for completion of the system (including pipe insulation) and will place it in operating condition.

M. MAINTENANCE

1. Periodic lubrication of moving parts (pumps, blowers, etc).
    - a. Locate all components requiring lubrication.
    - b. Apply lubrication to components as specified by manufacturers.
2. Filter change.
    - a. Remove grill or cover plate as needed.
    - b. Remove old filter. Clean with air jet or replace as recommended by manufacturer.
    - c. Replace filter and grill or cover.
3. Clean collector glazing.
    - a. Home-owner.
4. Descale heat exchangers (water side).
    - a. Remove heat exchanger by uncoupling joints or unsoldering.
    - b. Flush with descaling agent.
    - c. Connect flow meter and pressure gauge and check back pressure. Compare with manufacturers specs.
    - d. Replace heat exchanger.
5. Flush open liquid collector loops and refill with clean solution.
    - a. Drain fluid from collectors and heat exchangers.
    - b. Recharge system with water and drain again.
    - c. Fill system with glycol or other recommended solution or fluid.
    - d. Insure all drain valves are closed and check pump to insure it is circulating through the collectors.
6. Deleted by experts.
7. Check antifreeze solution strength and PH in liquid closed loop systems.
    - a. Drain small quantity of heat exchange fluid into small container.

    b. Inspect color and/or check PH with litmus paper or test kit.
    c. Check specific gravity of solution with hydrometer (if glycol used).
    d. Replace fluid if necessary, or replace lost fluid.

8. Deleted by experts.
9. Replace sacrificial corrosion elements and other system components which are periodically consumed.
    a. Drain fluid from system below level where sacrificial element is located. Insure storage tank is isolated from service water pressure.
    b. Unscrew or remove sacrificial element and replace with new element.
    c. Refill system and place in operating condition.
10. Check tracking orientation of concentrating collectors.
    a. Inspect collectors at various intervals over a day to insure that the focal point of the concentrator is on the collecting surface.
11. Check liquid levels in expansion and storage tanks.
    a. Home owner.
12. Check normal positions of motorized valves and dampers.
    a. See L.2
13. Monitor flowrates and temperature differentials to test system operations.
    a. Check or estimate insolation rate and check flow rate (if flow meter is built in).
    b. Monitor temperature differential across collector by attaching temperature probes to collector inlet/exit.

   c. Calculate instantaneous collector efficiency and/or flow rate using manufacturer's collector performance curve and compare all results.

14. Check for degradation of pipeline insulation.
    a. Visually inspect pipe insulation exterior.
    b. Remove short section of insulation and check for moisture or deterioration.
    c. Replace insulation.

15. Check seals on pumps (for leaks).

TOOLS AND EQUIPMENT

(A) Oil can or grease gun.
(B) Plumbing equipment.
(C) Test equipment: Pressure gauge, flow meter, VOM, Hydrometer, PH Test kit, thermometers, simple pyranometers.
(D) Complete tool kit including screw drivers and wrenches.
(E) Ladder.

MATERIALS AND COMPONENTS

(A) Filters.
(B) Descaling agent.
(C) Manufacturer's equipment specification.
(D) Glycol or other heat exchange fluid.
(E) Sacrificial element (anode rod).

REQUIRED KNOWLEDGE

(A) Science
    (1) Chemical equilibrium.
    (2) Acid-base reactions.

  - (3) Astronomy.
  - (4) Thermodynamics.
  - (5) Electrochemistry.
  - (6) Physics.
- (B) Mathematics.
  - (1) Algebra.
  - (2) Arithmetic

APPENDIX M

TASKS ANALYSIS, SOLAR TASKS

This appendix contains a refined analysis of the tasks that require training in solar-related skills. Skills that a worker would need to complete each task are listed and referred to specific tasks.

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
A. CALCULATE HOT WATER LOAD 1. Determine monthly average ground water temperature	a. Obtain ASHRAE Handbook etc., or contact water utility for temperature data.	Library skills Temperature measurement Seasonal variation	Interpret tables
2. Determine design hot water temperature.	a. Determine from building plans what types of appliances are in use, and what water temperatures they require.	Library skills Blueprint reading Temperature	Interpret tables Addition Subtraction
3. Determine hot water requirement for persons.	a. Using Uniform Solar Energy nomography or other reference, apply the number of persons using hot water consumed, or multiply number of persons by 20 gallons per day.	Nomograph interpretation Temperature Energy units	Interpret tables Multiplication Addition Interpret graphs
4. Determine hot water requirement for applicances.	a. Repeat above procedure for appliances using nomograph, or contact manufacturer or distributor of appliances for hot water demand.	Nomography Temperature Energy units	Addition Multiplication Interpret graphs Interpret tables

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
5. Determine BTU requirement of monthly hot water load.	a. Read BTU requirement from nomograph, or multiply gallons used per day by the design temperature minus the supply water temperature and by 8.3 lbs. per gallon.	Temperature Nomography Heat transfer Specific heat	Multiplication Division Addition Subtraction
D. CHOOSE COLLECTOR TYPE			
1. Determine average operating collector fluid temperature.	a. Obtain manufacturers' specifications on collector performance.	Energy units Temperature Heat transfer Light transmission Factors effecting efficiency	Interpret graphs Interpret tables
	b. From collector manufacturers' specs obtain average operating collector fluid temperature that corresponds to design demands for temperature out of collector.	Temperature Nomography Heat transfer Factors effecting efficiency	Interpret graphs Interpret tables
	c. Enter this temperature on work sheet.		

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
2. Determine design ambient temperature and insolation.	a. Obtain ASHRAE Handbook of Fundamentals or other source of meteorological and insolation data.	Meteorology Temperature Astronomy	Arithmetic Trigonometry
	b. Look up for design month the ambient temperature and insolation values.	Chart interpretation	Addition Subtraction Multiplication Trigonometric functions Division
	c. Enter values on worksheet.		
3. Determine flat-plate and concentrating collector efficiencies for design conditions.	a. Obtain manufacturer's specifications for collector performance.	Heat transfer Efficiency Insolation Light transmission	Interpret graphs Interpret tables Arithmetic
	b. Read design conditions from worksheet.	Temperature	Interpret tables

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
	c. Enter performance graph on bottom axis at point defined by $\frac{T_{in} - T_{ambient}}{\text{Insolation}}$ and go up to curve then horizontally to vertical axis and read collector efficiency.	Temperature Nomography Insolation efficiency	Interpret graphs
	d. Enter results on worksheet.		
4. Determine cost per square foot of collector types.	a. Obtain collector cost from manufacturers or sales outlet.	Interpret value	Arithmetic
	b. Obtain effective solar absorber area from manufacturers literature.	Effective area	Interpret graphs Interpret tables
	c. Divide cost of total collector by effective solar absorber area to get $/ft^2 collector.	Interpret value	Division
	d. Enter results in worksheet.		

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
5. Calculate \$/BTU.	a. From D.3 above enter collector efficiency and design insolation in equation below $\frac{\$}{BTU} = \frac{\text{Cost/Effective Area}}{\text{Insolation x Efficiency}}$	Energy units Value Effective area Insolation	Equation manipulation Algebra
	b. From D.4 above enter collector cost per square foot of absorber area in equation above.	Value Efficiency	Equation manipulation Algebra
	c. Solve equation for $\frac{\$}{BTU}$	Value Energy Units	Equation manipulation Algebra
	d. Enter results in worksheet.		
6. Choose collector type with lowest energy cost.	a. From list of \$/BTU in D.5 above choose collector with lowest \$/BTU	Value	Data comparison
E. CALCULATE SOLAR GAIN ON UNIT AREA BASIS.			
1. Determine collector tilt for application.	a. Find local latitude from maps or atlas.	Map reading Geography Latitude	Interpret graphs

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
	b. Determine solar application from client or blueprints and specifications as to whether it is space heating plus water heating.	Blueprint reading Energy units	
	c. If space heating only, a thumb rule for collector tilt plus 15 degrees will be appropriate to make use of the winter sun's position in the sky.	Sun/earth relationship	Arithmetic Trigonometry
	d. If water heating only, a thumb rule for collector tilt equal to the latitude will allow year round use of collector.	Sun/earth	Trigonometry
	e. If combination of space heating and water heating is required, the tilt is the same as that of space heating only.	Sun/earth	Arithmetic Trignonmetry
	f. Enter results in worksheet.		

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
	curve and compare all results.		

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
2. Determine for each month average hourly insolation for tilt and latitude.	a. Obtain ASHRAE insolation tables.	Energy units Insolation	Interpret tables
	b. Obtain local latitude and tilt from E.1 above.	Latitude Tilt	Interpret tables
	c. Enter ASHRAE tables for local latitude or closest latitude for which there is a table in the month of January.	Latitude Nomography Meteorology	Interpret tables
	d. Read across to tilt closest to that determined in E.1 above.	Tilt Latitude	Interpret tables
	e. Enter in worksheet the hourly values for insolation.		
3. Determine for each month average ambient daylight temperature.	a. Obtain ASHRAE Handbook or other source of temperature data.	Temperature Meteorology Latitude	Interpret tables
	b. Enter table for geographic location and list average daily daylight temperature.	Temperature Geography	Interpret tables

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
4. Determine monthly collector efficiency from collector performance curve.	a. Obtain manufacturers efficiency curves.	Efficiency Heat transfer	Intrepret graphs
	b. Using the following equation $x = \frac{T_{in} - T_{ambient}}{I_{design}}$ determine "x" value using design insolation, collector design inlet temperature, and ambient temperature.	Temperature Insolation	Algebra Equation manipulation
	c. Enter manufacturer's efficiency curves, then horizontally to vertical axis and read collector efficiency.	Efficiency Nomography	Interpret graphs
	d. Follow above procedure for each month of the year.	Temperature Nomography Efficiency	Algebra Interpret graphs
5. Determine monthly clear day collector heat gain in BTU Ft.^{2} - hr.	a. From E.2 above sum all hourly insolation values greater than $\frac{125\ BTU/hr}{ft.^2}$	Insolation	Addition

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
	b. Multiply daily clear day insolation (above) by collector efficiency from E.4 above.	Insolation Efficiency	Multiplication
6. Determine for each month average daily daylight collection hours.	a. Obtain ASHRAE Handbook.	Astronomy Sun/earth relationship	Interpret tables
	b. Enter tables for closest latitudes and read number of daily daylight hours.	Latitude Sun rotation	Interpret tables
7. Determine haze factor for locality.	a. Obtain local meteorological data from colleges, airports, Federal Government, or State Government, etc.	Meteorology	Interpret tables
	b. Look up haze factor for locality.	Meteorology Light scattering Light absorption	Interpret graphs Interpret tables
8. Determine average monthly percent of sunshine.	a. Subtract haze factor % from 100% to obtain % sunshine.	Definition of percentage	Multiplication Subtraction

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
9. Calculate unit monthly solar gain in BTU/Ft.^{2}, using information obtained in above steps.			Algebra

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
F. DETERMINE MAXIMUM AVAILABLE COLLECTOR AREA			
1. Determine roof space dimensions.	a. Obtain blueprints or drawings (to scale) of building.	Blueprint reading	Interpret graphs
	b. Using engineers or architects scale or actual on site measurement with tape measure, measure all areas of roof that give good southern exposure.	Blueprint reading Area Mensuration	Arithmetic Trigonometry
	c. Enter this area on worksheet.	Area	
2. Determine ground space dimensions.	a. Obtain tape measure.	Toolcraft	Basic measuring skills
	b. At the site, measure length and width of ground space available for storage tank or collector placement.	Mensuration Length Width	Arithmetic Trigonometry
	c. Enter area on worksheet.	Area	
3. Determine shaded spaces.	a. Obtain sun angle locator box.	Toolcraft Simple machines	
	b. Positioning yourself so that you are eye level with the bottom of the proposed collector array, use sun angle locator box, positioned parallel with long axis of roof, to find time of year and position of shade devices.	Sun/earth relationship Simple machines	Angles Trigonometry

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
	c. Mark areas that will be shaded on roof/ground diagram.	Simple machines	Arithmetic
	d. Measure these areas.	Mensuration	Arithmetic
4. Determine collector physical dimensions.	a. Look up dimensions on manufacturer's specification sheet.	Area Length Width	Interpret tables Arithmetic
5. Allow for proper spacing of collectors on flat roof.	a. Obtain ASHRAE Handbook.	Mensuration Area	Arithmetic
	b. Look up solar altitude at 10:00 a.m. on December 21.	Sun/earth relationship	Angle measurement
	c. On separate sheet of paper draw to scale, side view of collector array with proper tilt and collector height.	Drafting Tilt	Trigonometry Angle measurement
	d. Using protractor, find the point on the north side of collectors where a line drawn at an angle equal to the altitude would just touch the upper edge of the collector.	Simple machines	Trigonometry Angle measurement
	e. Measure the distance from the back of the collector array to this point with architects or engineers scale.	Mensuration Length	Linear measurement
6. Allow for proper collector tilt and azimuth.	Tilt Azimuth	Trigonometry	

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
7. Calculate maximum possible collector area in square feet.	a. Subtract from gross area those areas that were not usable.	Mensuration	Arithmetic
G. DETERMINE OPTIMUM COLLECTOR AREA			
1. Multiply given collector area by monthly unit solar gain to obtain monthly solar gain in BTU.	a. Obtain collector area from F.7. above.	Energy units Mensuration	
	b. Obtain monthly unit solar gain from E.9.	Solar Insolation	Equation manipulation
	c. Multiply these numbers together.	Area Solar insolation	Arithmetic
2. Obtain monthly useful solar gain by taking the lesser of the monthly solar gain and the monthly total load.	a. By looking at a column of monthly useful solar gain and a column of monthly total load enter the lesser of the two numbers for each month in a third column.	Nomography	Interpret tables Arithmetic
3. Obtain the typical annual useful solar gain in M BTU by summing the monthly totals and dividing by 10^6.	a. Add all the numbers in the third column in G.2. above.	Energy units	Arithmetic
	b. Divide this number by 10^6 to obtain M BTU.	Insolation	Arithmetic
4. Determine auxiliary fuel efficiency.	a. Obtain written data on fuel efficiency if possible.	Efficiency	Arithmetic
5. Obtain auxiliary fuel efficiency.	a. Multiply value in G.4. above by annual useful solar gain.	Insolation	Arithmetic
6. Determine cost of solar system.	a. Obtain collector cost information from manufacturers.	Value	Arithmetic

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
	b. Multiply collector cost by the number of collectors to get solar collector costs.	Value	Multiplication
7. Determine the mortgage interest rate and term.	a. Obtain list of mortgage rates from local building institution.	Mortgage rates	Arithmetic
	b. From this list determine mortgage rate based on system cost and lifetime.		
8. Determine cost and inflation rate of auxiliary fuel.	a. Obtain list or table of local utility rates.	Energy units Costs	Interpret tables
	b. From this table determine rate which applies to the specific application (residential, commercial, etc.)	Rate structure	Arithmetic Interpret tables
	c. Obtain from local Public Utilities Commission estimates for fuel inflation rates.		
	d. From this information determine which rate applies.	Rate structure	Interpret tables Arithmetic
9. Calculate life cycle value of solar system.	a. Enter data collected above in following formula:	Value	Algebra
	\$ = Capital cost of solar system		
	(cont'd on following page)		

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
	$ = Capital cost of solar system including tax incentives or other factors as reflected in $/BTU + present value of fuel cost over lifetime of system + present value of stream of maintenance costs over lifetime of system		
10. Iterate above steps with different collector areas to obtain maximum life cycle value.		Value	Algebra
H. DESIGN FLUID FLOW SYSTEM			
1. Determine proper storage size and location.	a. Locate outside tank in area protected from the elements. Locate inside in tank in mech room insulated from conditioned space if used in summer.	Heat transfer Temperatures Insulation principles	Basic measuring skills
	b. Determine application BTU/Hr design load requirements from A, B, & C as applicable.	Heat transfer Temperature	Equation manipulation

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
	c. Determine hours of storage required for application, typically 24 hours for heating and hot water and three to four hours for cooling.	Specific heat Heat transfer	Equation manipulation
	d. Determine BTU storage requirement by multiplying hours of storage by BTU/Hr requirement.	Specific heat Heat transfer	Multiplication Equation manipulation
	e. Determine design maximum storage temperature and minimum useful storage temperature.	Temperature Heat transfer	Equation manipulation
	f. Divide BTU by the difference between maximum and minimum temperatures and divide the result by 8.33 to obtain storage size in gallons. $GAL = \frac{BTU}{8.33 \times T}$		Division Equation manipulation
2. Integrate solar and conventional systems.	a. For air systems, determine proper location of solar duct tie-ins. For liquid systems, determine location of water coil in conventional ductwork.	Blueprint reading	Basic measuring skills
3. Design system controls and operation modes.	a. Use two stage thermostat to bring on solar first and conventional equipment second.	Control theory Flow of electrical current	

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
	b. Use temperature sensors and relays to prevent the circulation of the solar working fluid to the load when the fluid is not hot enough to help meet the load.	Temperatures Electrical circuitry	Interpret diagrams
	c. Use a differential control and sensors to ensure that the solar collectors recharge storage and do not degrade it.	Electrical circuitry Bi-metal principles	
	d. Use a motorized valve or check valve to ensure that storage is not degraded by thermal siphoning backflow.	Fluid flow Electrical circuitry	Interpret diagrams
	e, Include relief valves, air vents, vacuum breakers, and tempering valves as necessary.	Piping design	Arithmetic
4. Size individual system components in accordance with collector size and load requirements.	a. Determine CFM and GPM for conventional equipment and solar collectors.	Pump characteristics Fluid flow Fan characteristics	Equation manipulation Arithmetic Interpret tables
	b. For liquid systems, choose water coil that meets BTU/Hr load requirements at design minimum useful solar supply water temperature.	Temperature Heat transfer Fluid flow	Arithmetic Algebra Comparison

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
	c. For air systems, choose air to water exchanger to meet domestic hot water requirements at collector design CFM and outlet temperatures.	Temperature Heat transfer Fluid flow	Algebra Arithmetic Comparison
	d. For liquid systems requiring a water to water heat exchanger between the collector and storage, determine collector fluid specific heat, GPM, and outlet temperature; and determine tank minimum flow over the exchanger surface and design inlet temperature. Refer to manufacturer for exchanger size.	Specific heat Temperature Heat transfer Fluid flow	Algebra Arithmetic
	e. Design duct and pipe sizes for required CFM and GPM not exceeding friction loss and velocity limits specified in ASHRAE handbook.	Fluid flow Piping design Duct design	Algebra Arithmetic Equation manipulation Interpret graphs Interpret tables
	f. Choose the smallest pump and fan models that exceed or equal design CFM and GPM at required static pressure and head.	Fluid flow Nomography Pump characteristics Fan characteristics	Interpret graphs Comparison Interpret tables
5. Prepare working drawings.	a. Determine schematic representation of system components: pipelines, valves, dampers, fans, pumps, storage, collectors, conventional equipment, etc.	System design Drafting	Interpret diagrams

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
	b. Draw wiring diagrams linking thermostats, relays, temperature sensors, and mechanical system components.	Electrical circuitry Drafting	Interpret diagrams
	c. Use building plans to determine physical location of components.	Blueprint reading	Interpret plans
6. Prepare materials and equipment specifications.	a. Determine lengths of various duct and pipe sizes needed.	Mensuration	Arithmetic Trigonometry
	b. Determine number and sizes of elbows, tees, gate valves, manual dampers, registers, and other small passive fittings for pipeline connections.	Mensuration	Arithmetic
	c. Determine number and sizes of motorized valves and dampers, pumps, fans, differential controls, thermostats, relays, relief valves, vacuum breakers, air vents, expansion and compression tanks, aquastats, and other small active system components.	Mensuration	Arithmetic
	d. Determine number and model of collectors, furnaces, air conditioning units, storage tanks, or other large system equipment.	Mensuration	Arithmetic Interpret charts

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
J. INSTALL COLLECTOR			
3. Mount each collector.	a. Obtain collectors from manufacturer.	Human relations	Interpret graphs Interpret charts
	b. Raise collector onto roof.	Mechanical advantage Simple machines Coefficient of friction	
	c. Place collector on mounting being careful not to damage copper heads or mountings.	Mechanical advantage Simple machines	Basic measuring skills
	d. Fasten collector to mounting per blueprints.	Knowledge of fasteners Simple machines Blueprint reading	Interpret diagrams
L. SYSTEM CHECKOUT			
2. Check out the system powered components.	a. Insure power is delivered to system components.	Flow of electrical current	Basic measuring skills Interpret meter scales
	b. Place system in all possible operating modes by manually switching control and/or shorting sensor wires.	Control theory Flow of electrical current Interpret wiring diagrams	
	c. Check operation of pumps, automatic valves and other components in all modes to insure their operation complies with the intended mode of operation.	Flow of electrical current Fluid flow Airflow Solenoid operation	Interpret scales
	d. Return control overrides to normal position.		

DUTY TASK	ACTIVITY	SCIENCE SKILLS	MATHEMATICS SKILLS
4. Calibrate and test solar temperature differential controls.	a. If control system is factory calibrated, inspect operation of system under various temperature and insolation conditions. Insure that system is operating in proper modes.	Temperature Solar insolation measurement Fluid expansion & contraction Bi-metal principles	Interpret scales
	b. If control is not factory calibrated, test by immersing sensors in water at various temperatures. Monitor water temperature with thermometer and check differential on and off temperatures and high or low limit functions. Use VOM to check position of relays.	Temperature Bi-metal principles Flow of electrical current	Interpret thermometer scales
M. MAINTENANCE			
12. Check normal positions of motorized valves and dampers.	a. See L.2		
13. Monitor flowrates and temperature differentials to test system operations.	a. Check or estimate insolation rate and check flow rate (if flow meter is built in).	Solar insolation measurement Fluid flow Pressure drop	Interpret scales
	b. Monitor temperature differential across collector by attaching temperature probes to collector inlet/exit.	Temperature Temperature measurement Thermocouple principles	Interpret scales
	c. Calculate instantaneous collector efficiency and/or flow rate using manufacturer's collector performance	Efficiency Fluid flow Heat transfer	Equation manipulation Interpret charts

APPENDIX N

CONTRACTORS COMMENTS

On the contractors' survey form a space was included for comments. This appendix contains a number of the comments received from contractors. The comments are un-edited except for the deletion of identifying names.

Dear Mr. Gibson:

I enjoyed filling out the enclosed questionnaire. I am very pleased to see someone is concerned about the need for trained personnel in the solar field.

In relation to training people for the solar field, is Navarro College offering any full time courses for undergraduate students? The reason I ask is I have a brother who finished his first year of college and is very interested in turning his education towards the solar field.

If Navarro College is not offering any full time training in solar, maybe you could furnish me with some colleges who are offering full time courses. (Not the 3 to 5 day sessions that many colleges are now presently offering.)

If there are any more questions you need answers for, I will be happy to assist you if I can. I would also appreciate an answer to the question of full time courses in the solar field because I would like to see my brother attend a school who is offering such courses.

Have a pleasant summer and may the sun always shine on the south side of your home.

Cordially,

Dear Mr. Gibson:

Concerning your recent letter to "Access the Need for Developing and Implementing Technical and Skilled Worker Training for Solar Energy Industry".

(____________________), I feel, is presently not qualified to supply you with the information you have requested.

We are a new company which is still in its research and development stages. In the near future we have a 30 unit condominium project in which we will install solar hot water applications; and in our new 2400 sq. ft. office complex to be constructed we plan to incorporate a complete solar application: hot water, space heating, and cooling.

As this project develops, (____________________) will be happy to contribute its findings to your study.

I believe that the task you are undertaking is a very important one. If the solar industry is to survive and prosper, it must develop qualified labor to keep pace with technology.

Please keep me advised of your progress and your findings. If I may be of further help to your project, do not hesitate to write or call.

Cordially,

Attn: Harold J. Gibson

Dear Mr. Gibson:

Because I feel very strongly about solar heat, I am enclosing a personal letter.

Our experience in the solar market gives us the same feeling we were exposed to with the heat pump market in the early sixties. The failures then, with the heat pump, should give us an insight to proper steps required to have a solar system that will work.

Solar collectors certainly will become the victims of improper installations if inadequate amounts of collectors are installed.

I have raised a few of the many problems that exist, and continues to exist, if manufacturers don't take proper control of their market place.

I certainly do hope we all voice our interests in this industry in the future.

Very truly yours,

CARPENTRY:

Developing Skilled Solar Technicians and Designers is definitely worthwhile and I suggest learning by building and operating your own water heating system and/or cool system for Navarro College. Just Do It!

We are operating 2 companies - one company, (____________________) is a general contracting firm, with primary emphasis on solar. Typically, we start with a customer and his lot, and custom design a home for that customer. We stress a heavy use of energy conserving materials and designs, as well as incorporating as much solar as possible into the home.

The second company, (____________________) is a solar manufacturing firm. We manufacture and sell flat plate collectors, as well as other solar related products. In addition, we market Fafco solar pool heating collectors.

Our primary goal is to consummate a "marriage" of solar and architecture. For that reason we maintain a staff of designers that are responsible for all architectural designs.

We look for the solar market to expand rapidly in the coming months. We have already done as much business in the first half of this year as we did in the prior 18 months.

Good, qualified installers will be at a premium in the coming months.

In order to "Assess the Need for Developing and Implementing of Technical Skilled Workers for the Solar Energy Industry", the questions should not be so broad so that it becomes difficult to answer. For example, the first question should ask about the last application that I was involved with, since I am currently research and developing the idea of radiant cooling. Incidently, I have only been with the firm for 2 months so that you can see how busy we are out here.

Currently I am in transit to open another regional branch office and I am familiar with the need in the field as I taught a 10-hour lecture series in Adult Education here at (________________________). If I can be of further assistance (I applaud your efforts), please contact through (___________).

From my own educational and vocational background I know what I would like to have in a designer or technician, and from my experience with the seminars, classes, lectures and societies that I've attended and joined, I do not believe many of these designers and technicians will be truly qualified. I hope your program will be the exception to the general rule.

My choice of candidates would be:

A good physics background with the ability to relate with daily activity. Stress on fluid mechanics and heat transfer. Calculus level in mathematics would be sufficient. Field work in mechanical engineering as well as classroom studies. Another prerequisite would be the ability to derive equations rather than memorize formulae. This is asking a lot, but I feel these qualifications would make a top employee who could grow to the top anywhere in solar work.

My main complaint with current solar studies is an excess of tables, calculations and formulae with a minumum of common sense and practical application.

Yours truly,

In Florida the solar markets are primarily domestic hot water and pool heating. These are relatively low technology and do not require substantial design efforts.

For larger hot water heating systems (commercial), I do the design work myself in conjunction with other building trades.

In the future, I will hire a graduate of a general engineering program and train him in the solar aspects myself.

For installation labor we employ experienced plumbers, due to local building codes.

In the event that the federal government passes tax incentives to stimulate the industry, there will be a shortage of trained installation personnel. This situation will exist for about 6 months, the time necessary to train an installer.

I will be more than happy to answer any future questions you may have.

Our experience has been that each system is unique. We sell to industrial, commerical and residential. The technicians would be valuable if they knew heating and air conditioning with solar application. Since the architects use engineering data, the application of their plans to installation, if not already provided for, would facilitate.

Let me know if I can be of any further help.

Regards,

P.S. Most urgently needed:

People who can call on potential prospects, arouse interest in solar advantages, assess the present system, design solar application to be used for particular system and ultimately close the sale! Thereafter, they would supervise installation and explain maintenance to the purchaser.

Thanks for the opportunity to respond to your questionnaire!

There is a need for solar technicians (sun plumbers) who can install, maintain and troubleshoot solar equipment. And there is a need for knowledgeable small businessmen (the guys on the corner) who can sell and service solar equipment on a par with T.V. sales and service. However, I feel that the most pressing need right now is for every builder of new buildings and home improvement contractors to be made knowledgeable of basic concepts of sun heating and cooling. This is where the greatest progress can be made - if every new building or additions to existing can be designed to take advantage of the natural energy of the sun.

I support your efforts to help establish a solar industry, and wish to help in any way I can. However, I'll bet that the same investment in time and energy put into a "Sesame Street"* approach to educate our kids rather than a university program would have a much greater effect on our future.

Enclosed is a brief description of our new home which speaks for the way I feel. Please examine it as there has been considerable thought gone into it. And pass it on to others who may be interested.

Thank you,

*Call it "Energy Street"

Comments:

We are establishing a tentative administrative force, a Sales Organization and an installation personnel group in anticipation of a sudden increase in sales and distribution of our Solar Energy equipment. Many inquiries are received from Solar Energy prospects who are planning to build new homes which will include Solar Energy equipment. This should result in sales when the government finally stabilizes the grant and tax incentive programs.

When the "explosion" erupts many people versed in the application of Solar Energy will be required to meet the demand for persons in all phases of the solar energy equipment business.

In my estimation -

The biggest need in manpower is now and will be a solar designer-draftsman (not a mechanical engineer - they tend to over design a system, causing increased prices).

The average plumber-fitter can install a system given a good detailed plan. The critical need is in figuring heat losses solar insolation, pipe sizing, pump sizing, piping layouts (valves, check valves, thermistors, flow meters etc.)

The next need is controls - design and wiring - almost every system is different and requires knowledge of what control to perform what function.

The solar installations are no piece of cake - each takes its share of de-bugging.

Hope I have been of some help.

Sincerely,

Suggest you start a "hands on" program of practical field experience. We found the 5 engineers we employed all missed certain elements of the schematics that were clearly and somewhat readily brought to our attention after the system became activated.

Good luck,

(________________), has just emerged from pilot production.

Certain of our manpower requirements are, therefore, preliminary and are under continuing review. A response from us in 6 months will yield more meaningful information.

However, we already perceive a need for trained solar installers and repair personnel. There is no question of a shortage of such people. We could use 1-2 such individuals now.

V. Would you hire a solar designer or installer if such a trained technician were available? Not yet If no, explain.

Still in development stage and training is taking place daily so to say you are trained in todays market is a mistake.

VI. COMMENTS: Basic training in heating design is a must. There are too many in field with no background in heating engineering.

V. Would you hire a solar designer or installer if such a trained technician were available? ___NO___ If no, explain.

Not enough need for one.

VI. COMMENTS:

I expect that plumbing and sheet metal subcontractors will do the work in the future.

V. Would you hire a solar designer or installer if such a trained technician were available? Yes If no, explain.

with qualification: would have to be experienced in conventional systems; insufficient volume to justify a solar specialist.

VI. **COMMENTS:**

V. Would you hire a solar deesigner or installer if such a trained technician were available? No If no, explain.

This will probably be our one and only solar job, if we ever complete this one.

VI. COMMENTS:

V. Would you hire a solar designer or installer if such a trained technician were available? NO If no, explain.

Skills generally are low level plumbing, HVAC carpentry, etc. We can train better and easier than the usual school.

VI. COMMENTS:

This is a low technology field (except for photovoltaic). We have easily trained technicians in 1 month to 6 weeks and designers to size systems etc. in two months.